THE UNIVERSITY OF ALBERTA

SURPLUS PATTERNS AND WATER SUPPLY ALTERNATIVES: COOKING LAKE MORAINE

by

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A THESIS

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DEDICATION

This thesis is dedicated to Glenda Woodburn, who waited for three years in Oklahoma and still married me.

ABSTRACT

In many areas of the Canadian Prairies spring snowmelt runoff is the major contributor to the yearly water surplus. In the Cooking Lake Moraine, where declining lake levels and poor water quality have limited the use potential of the area, it was thought that better management of spring snowmelt flows might yield extra water to the lakes to halt declining levels.

In order to study the spring surplus patterns in the Cooking Lake Moraine, ten test basins were chosen. Estimates of snow melt runoff for the 1975 and 1976 field seasons were made using procedures described by C. W. Thornthwaite. In each of the field seasons, the actual runoffs from the sites were gauged and compared with predicted results.

In both field seasons precipitation was low and the measured amounts of runoff exceeded predicted amounts. The discrepancies were due largely to a lack of consideration of the effect of drifting in making runoff predictions. After observing the effects of drifting it was possible to estimate net increases of from two to five centimeters of runoff in areas which received drifted snows.

Other aspects of the water balance were also studied, especially the anomalously positive balance of the Hastings Lake basin. It appears that the Hastings Lake basin has a number of features which contribute to its more favorable balance including a larger effective drainage basin increased partly by artificial drainage, drainage advantages because of topography and a clearing and land use pattern which results in greater yields than in other basins.

In the course of the study it became evident that there were

several alternative means of water supply that might be used. Large scale transfer of water had been suggested previously, but would be costly and might provide much more control than was necessary. In this study several alternative means of supplementing supply, including small scale diversions, phreatophyte removal and snow cover management were studied. Though none of these methods could be fully tested concerning their physical potentials, it was estimated that these water management alternatives offered a viable option to large scale, costly pipeline schemes.

ACKNOWLEDGEMENTS

There are many people and agencies whom I would like to thank for aid and assistance throughout the course of the writing of this thesis.

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The contribution of Dr. A. H. Laycock as advisor cannot be understated. Without his direction in all phases of research and writing, suggestions and encouragement, this thesis might never have been written. I would also like to extend my appreciation to the other members of the examining committee, Dr. E. P. Lozowski of the Division of Meteorology and Dr. D. N. Gallup of the Department of Zoology, for their comments and suggestions which improved the quality of the final manuscript.

A special thanks must also be extended to Wanda Lowe of Pierre, South Dakota for a superlative typing job. Her excellent work on typing the original manuscript and in making corrections saved much time and effort.

During the writing of the thesis, several friends and acquaintances provided help and companionship which I could not have done without. I would like to thank Gregg Wiche, Dr. Sheila Brown, Colin Jeffares, Jack Park, Brian Waddell, Richard Benfield, Barry Soklofske, Robert Hutchinson and Team Geography Hockey.

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CHAPTER I

INTRODUCTION

The Cooking Lake Moraine is an area where declining lake levels and water qualities have severely hampered the water use potential of the area. It is an area only a short distance from the city of Edmonton and in this time of increasing need for outdoor recreation facilities the Cooking Lake Moraine is being looked at as a prime area for expanding recreational development. If this is to come about, a number of land use management decisions must be made.

The Cooking Lake Moraine Study Area, as delineated by the Alberta Department of Environment, is located east and southeast of the city of Edmonton (Figure 1). It is nearly 1800 square kilometers in area and is elongated in shape from north to south. It runs generally from north of Elk Island National Park in the north to beyond the Miquelon Lakes in the south and from just west of Cooking Lake in the west to east of Beaverhill Lake (Figure 2). It includes the basins of several lakes which are believed to have once formed a chain of drainage. It included Larry, Joseph, Oliver, Ministik, Cooking, Hastings and Beaverhill Lakes (Figure 2). Miquelon Lake in the south may have been part of the chain at one time but evidence of this is weak and in dispute.

There were several reasons for selecting the study area. Beginning in 1971, because of public concern over declining lake levels, the provincial government began a land management study on the Cooking Lake Moraine. The study includes research into many physical aspects of the area including water balance, water quality and groundwater studies. This study is one of a number of studies made in conjuction with the University of Alberta Water Resources Centre. The study was

FIGURE 1

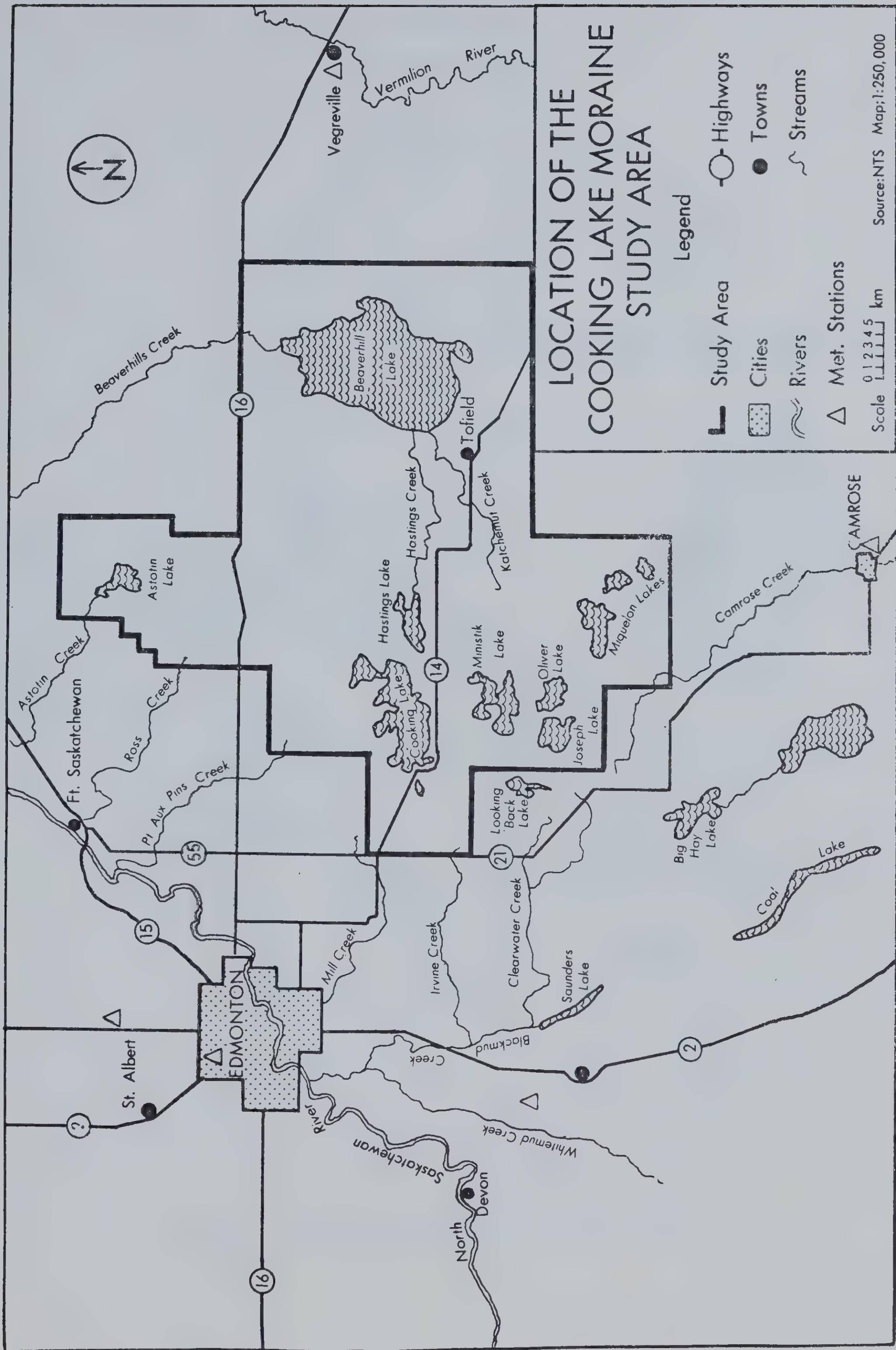
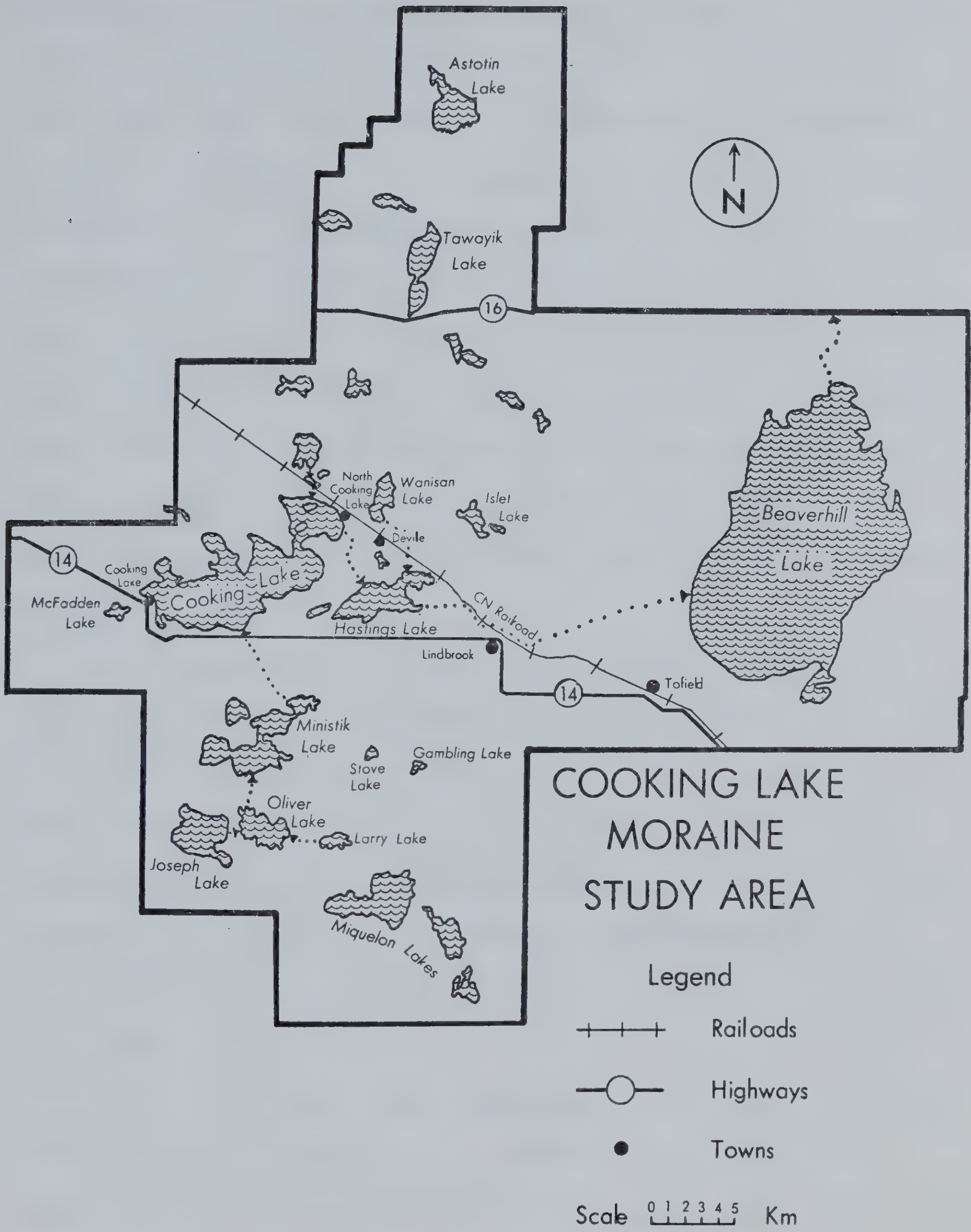

LOCATION OF THE
COOKING LAKE MORAINE
STUDY AREA
Legend
Study Area
Cities
Rivers
Met. Stations
Highways
Towns
Streams
Scale 0 1 2 3 4 5 km
Source:NTS Map;1:250,000
Vegreville
Vermilion River
Beaverhills Creek
Beaverhill Lake
Tofield
Hastings Creek
Katchemut Creek
Astotin Lake
Astotin Creek
Hastings Lake
Cooking Lake
Ministik Lake
Oliver Lake
Miquelon Lakes
Joseph Lake
Looking Back Lake
Camrose Creek
CAMROSE
Big Hay Lake
Coal Lake
Ft. Saskatchewan
Ross Creek
Pt Aux Pins Creek
Mill Creek
Irvine Creek
Clearwater Creek
Saunders Lake
Blackmud Creek
Whitemud Creek
EDMONTON
St. Albert
Saskatchewan River
North
Devon
16
14
55
21
15
2

FIGURE 2



Indicates historical flow pattern

Source : NTS Map;1:250,000

funded by Environment Canada and the Alberta Provincial Department of Environment on a grant administered by Dr. A. H. Laycock. It will be concerned with clarifying aspects of the water balance of the moraine area. Other theses which were done in conjunction with the University of Alberta Water Resources Centre include studies concerning estimation of snowfall patterns using Landsat I imagery (Witter, 1976) and lake level fluctuation modelling (Crawford, 1976). In addition, inventory studies commissioned by the provincial government were made by various consulting firms into the areas of wildlife carrying capacity, recreation potential (Shelly, 1975), water demand (Stanley and Associates, 1974), and industrial, urban and agricultural use. Because of these studies a great deal of useful information has become and will continue to become available.

When making a study of water balance, accurate meteorological records are necessary. While there are few meteorological records for the moraine, there are several stations in the area surrounding the moraine which have quite complete records. These stations give a reasonably accurate picture of moraine conditions. Records from the Edmonton International, Edmonton Industrial and Edmonton Namao Airports, and the towns of Camrose and Vegreville provide sufficient data for a number of years (Figure 1).

In every study where field records play an important part, accessibility to the field area must be considered. The center of the Cooking Lake Moraine is only 40 kilometers from the city of Edmonton, allowing frequent visits to be made during the field season.

1.1 Objectives

The objectives of the author were to more accurately define the

parameters which affect the water balance of the Cooking Lake Moraine and interpret the results. An analysis will be made of each component of the water balance equation and how the physical characteristics of the moraine affect each of them. It is hoped that the final result will give more insight into the water balance with specific attention being given to surplus from snowmelt and how this surplus might be used to maintain more acceptable water levels and qualities.

Although it had been discussed earlier, the water balance was most clearly described by C. W. Thornthwaite in 1948 (Thornthwaite, 1948). In a series of articles from 1948 to 1957 he described an equation with which net gains and losses of water from a region might be estimated. This water balance equation was given as:

$$\text{Precipitation} = (\text{Potential Evapotranspiration} - \text{Deficit}) + \text{Surplus} \pm \text{Storage Change}$$

The equation and the individual components will be dealt with in greater detail in Chapter II, however a brief description of the components is appropriate at this time. Precipitation is considered to be rain, snow or any other moisture from the atmosphere. Potential evapotranspiration is the amount of moisture lost by evaporation and transpiration when soil moisture supplies are not limiting. Deficit is the difference between potential evapotranspiration and the amount of moisture from precipitation and moisture storage that is actually available for evapotranspiration. Surplus is the amount of water in excess of evaporation and transpiration demands when soil moisture is at field capacity and may show up as surface runoff or groundwater flow. Storage change refers to the difference in the amount of moisture held in storage from the beginning to the end of a time period,

for most purposes between January 1 and December 31.

Throughout the Prairie Provinces of Canada the major portion of the surplus component in most years is found in spring snowmelt runoff. Since there is little or no loss of water by melting during the winter, great amounts of moisture may be stored in the snowpack for a quick release in spring. The amount of runoff is dependent upon many factors. Included are climate related factors such as precipitation and evapotranspiration as well as physiographic features such as soil and surficial materials. Also playing a significant role in the water balance of a region are the variables of land use and vegetative cover and type.

The initial purpose of the author in this thesis is to define the amount and quality of snowmelt runoff in and near the Cooking Lake Moraine. The end result should be a more accurate definition of one parameter of the Thornthwaite water balance equation.

Since the initial purpose of the author in the thesis is to determine the feasibility of using local snowmelt water as a means of halting the decline in lake levels, the study would not be complete without the inclusion of reference to other possible means of improving supply. In conjunction with the possibility of using local snowmelt waters, some means of modifying snow cover to increase yields will be suggested. Also included will be the possibilities of interbasin transfer of water.

1.2 Procedures

The first problem faced upon undertaking field work was that of delimiting the basins to be studied. Since the entire moraine study area (Figure 2) is in excess of 1700 square kilometers, it would not be feasible to make an exhaustive study of the entire area. Instead,

two subdrainage basins were chosen.

The drainage basins of Hastings and Joseph Lakes were chosen because they are representative of different parts of the moraine. When there was flow between the lakes, Hastings Lake was the last lake in the sequence within the actual hummocky disintegration moraine. Outflow from Hastings Lake was into Hastings Creek and on to Beaverhill Lake (Figure 2). It has one of the largest drainage basin to lake area ratios of the lakes in the moraine (approximately 10:1). The total basin area is approximately 90 square kilometers compared to 8.71 square kilometers of lake area. This area includes a number of small sloughs and Sisib and Coleman Lakes which are virtually sloughs. In times of below average precipitation there is no outflow from these depressions and the drainage basin to lake area ratio is reduced to a figure of approximately 3 or 4:1. While there has been some clearing for agricultural purposes, much of the basin remains under forest cover, especially south of the lake. Along with clearing for agriculture, a number of small sloughs have been drained in full and in part for use as hay meadows.

Hastings Lake is an anomaly when compared with the rest of the lakes in the study area. While the levels of other lakes have declined in recent years, the level of Hastings has remained relatively constant and outflow occurs in the wetter seasons. It is only .5 meters below 1916 levels and is over 2 meters higher than the level in 1950 (Stanley and Associates, 1974).

Also chosen for this study was the Joseph Lake Basin. It is located in the southwest part of the study area. It is a small basin of only 32.1 square kilometers, approximately 9.0 of which is lake area.

Most of the Joseph Lake drainage area is in ground moraine with only the eastern edge being part of the hummocky disintegration moraine. Because of this there are few depressions and sloughs within the basin which do not contribute annually to the lake drainage.

The Joseph Lake basin is in good contrast to the Hastings basin since it is nearly all in agricultural use (78% of non-lake area). In addition it has a relatively small drainage basin to lake area ratio (3.5:1) compared with Hastings Lake.

To determine the effect of land use on snowmelt runoff, 10 test plots were chosen. Of the 10 sub basins chosen, one was in the drainage basin of Cooking Lake, six were in the drainage basin of Hastings Lake and three were located in the Joseph Lake basin. The sites were chosen with respect to representative land uses. The sub-drainage basins were delimited using air photographs as well as field checking both before and during the field seasons. The land uses of each individual test plot, presented in Chapter IV, were derived from an air photo mosaic of the study area prepared by Mr. J. O. Park for the Alberta Department of Environment.

Snowmelt runoff was gauged at a number of corrugated metal culverts in the moraine area. The culverts were chosen as gauging sites for a number of reasons. One is that they provide an inexpensive method of obtaining reasonably accurate results. A number of studies show that flow volumes can be accurately gauged at these culverts (Norman and Bossy, 1970, Neill, 1962, Searcy, 1965, Carter, 1957). There is no cost involved in installation and access is no problem since most channel drainage is under roads. Another reason is that they provide well-defined, constricted channel flow in an area where

there are few well established drainage channels.

Measurement of runoff began at the first sign of melting in both field seasons, 1975 and 1976. Measurements were taken every day during heavy melt periods and at least every other day during the beginning and end of the melt periods.

Gauging was done by two methods. Some measurements were made using a pygmy flow meter. The pygmy meter is a hand held, cup type flow meter especially designed for gauging small volumes of flow. When the pygmy meter was unavailable or inappropriate for use another method was substituted. It involved placing a large twig or stick, large enough to be unaffected by wind, in the main current of the stream and timing it over a known distance (usually the length of the culvert). This gave the velocity of flow. The depth of water at each end of the culverts were taken and averaged to obtain the cross sectional area. This figure multiplied by velocity gave unadjusted discharge. This figure was reduced by thirty per cent to account for frictional drag around the perimeters of the culverts. This final figure was taken to be instantaneous discharge.

As a supplement to the study, water quality samples were taken during the 1976 field season. The samples were taken from four of the test sites and were then taken immediately to the Department of Zoology, University of Alberta water chemistry laboratory where the samples were analyzed.

1.3 <u>Anticipated results</u>

Snowmelt runoff comprises the major portion of yearly water surplus in most years in the Edmonton region. It is the purpose of this study to determine amounts of runoff in the Cooking Lake Moraine.

Estimates of runoff can be made but only actual measurements can show how much water is available and can confirm procedures used in estimating surpluses. It is hoped that the study will show which areas can contribute the most runoff and exactly how much water is available to supplement lake levels. Consolidation of snowmelt waters including redirecting melt and some management of snow cover as well as possible drainage improvements might contribute greatly to the stabilization of lake levels.

As will be explained later in a more detailed description of the Thornthwaite water balance equation (Chapter II), one of the major factors affecting runoff is the amount of water plants have access to in soil moisture storage. The amount which can be held differs with vegetative cover, largely because of different depths of rooting. Meteorological factors also affect the amount of water available. As can be seen from precipitation and evaporation tables (Appendix 1), there were major deficits due to evapotranspiration having greatly exceeded precipitation during the last half of 1974. Precipitation during the fall and winter of 1974-75 was insufficient to completely recharge soil moisture storage levels. The situation was much the same in the 1975-76 field season. In such situations it would be expected that most of the spring snowmelt would go to soil moisture recharge leaving very little surplus for runoff. Some runoff does take place, however, and the determination of where and why it does take place can contribute greatly to our understanding of local water balance patterns.

Although below average amounts of runoff might not be as desirable as near average or above average conditions for a study of this sort,

the conclusions drawn can still be useful. Winters with little snowfall, such as the two past, are part of the long term climate of a region. It is probable that the main reason for the decline in lake levels is due to climatic trends. In any management program it must be expected that these dry years will occur. In this context it is important to determine runoff patterns in years of below average precipitation as well as in years of far above normal precipitation, even though the major supply contributions would be made in the latter years.

It is important that we know how much surplus is available in the drier years and how we might most effectively use it in management. In the drier years, conservation of, and perhaps addition to, the limited supply available may be very significant and conditions may be improved for more effective runoff responses in the wetter years. It is possible to determine where the most effective responses are when surpluses are available. These topics will be discussed in Chapters V and VI.

It is hoped that the information presented in this study will give a better overall view of the water balance for the Cooking Lake Moraine area. The information presented might then be used as the basis for further watershed management studies.

CHAPTER II

PHYSICAL CHARACTERISTICS

2.1 General

The Cooking Lake Moraine Study Area, as outlined by the Alberta Department of Environment covers an area of 1795 square kilometers. It is situated between approximately 53°15' and 53°45' north latitude and 112°40' and 113°10' west longitude (Figure 1). The area selected for more intensive study covers an area of about 500 square kilometers in the southern portion of the moraine. It encompasses the lakes which fill some of the larger depressions in the moraine and which are most involved in discussions of water management policies.

The hummocky disintegration moraine is a distinct topographic feature of the area. It is higher than the surrounding land, reaching an elevation of over 792 meters above sea level in the southeast. It has a gentle northward slope to Cooking Lake which is at an elevation of just over 730 meters. This compares with Beaverhill Lake in the east and the city of Edmonton in the west which are around 670 meters above sea level (Canada Topographic Series - Sheet 83H).

The climate of the area is continental (Longley, 1967). Summer temperatures (April through October) average 10°C while winter temperatures average -10.7°C (Edmonton International Airport). July is traditionally the warmest month averaging 16.1°C. January is the coldest month with an average of -16.3°C (Edmonton International Airport 1975 Summary). Precipitation averages approximately 45.90 centimeters with approximately 26% falling as snow and 74% falling as rain.

The physical characteristics of the Cooking Lake Moraine will be

discussed in greater detail in other sections of this chapter as well as in Chapter V.

2.2 Bedrock Geology

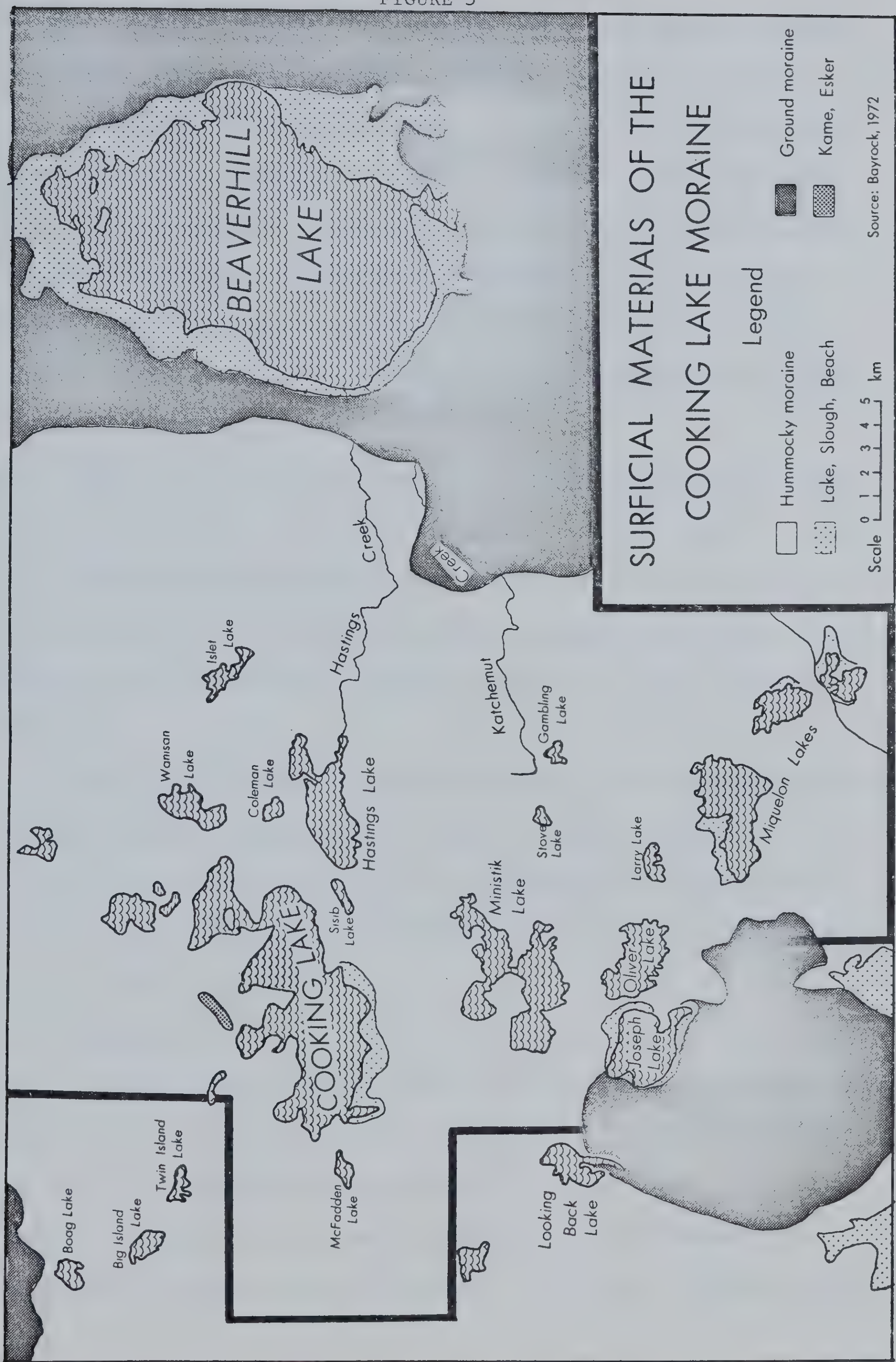
Most of the Cooking Lake Moraine is underlain by bedrock of the Edmonton formation. The Edmonton formation is of late Cretaceous age, formed approximately 65 million years before present (Carlson, 1967). The formation is composed mainly of clayey sandstones and bentonitic shales. There are beds of ironstone and coal seams found in the formation as well. The sediments comprising the Edmonton formation are almost exclusively non-marine. The formation has a dip of a few tens of feet per mile to the southwest (Research Council of Alberta, Map No. 35, 1972, Carlson, 1967, Atlas of Alberta, 1969, pp. 6-7).

The bedrock topography was determined mainly by erosion during Tertiary and late Pleistocene times (Carlson, 1967, Farvolden, et. al., 1963). The Cooking Lake Moraine area was in the headwaters of the Vegreville bedrock drainage channel (Farvolden, et. al., 1963). The channel drained toward the north east. It was separated from the Beverly bedrock drainage channel immediately to the west by the Cooking Lake Divide which ran approximately along the western edges of where the major lakes of the moraine are located now. Bedrock elevations in the headwater area near the divide are approximately 700 meters above sea level (Farvolden, 1963, Maps accompanying Carlson, 1967).

2.3 Surficial Materials

Glaciation of the area occurred during the Wisconsin stage. The area was covered to a thickness of over 1.5 kilometers. The glacier advanced from the north or northeast approximately 40,000 years before

FIGURE 3


SURFICIAL MATERIALS OF THE
COOKING LAKE MORAINE
Legend
Hummocky moraine
Lake, Slough, Beach
Ground moraine
Kame, Esker
Scale 0 1 2 3 4 5 km
Source: Bayrock, 1972
BEAVERHILL LAKE
Hastings Creek
Creek
Katchemut
Islet Lake
Wanisan Lake
Coleman Lake
Hastings Lake
Gambling Lake
Stove Lake
Larry Lake
Miquelon Lakes
Ministik Lake
Sisib Lake
COOKING LAKE
Oliver Lake
Joseph Lake
Looking Back Lake
McFadden Lake
Twin Island Lake
Big Island Lake
Boag Lake

present. Glacial retreat was largely by means of stagnation (Bayrock and Hughes, 1962, Atlas of Alberta, 1969, p. 12, Stelck, 1967).

Nearly all of the Cooking Lake Study Area is covered by glacial till (Figure 3). In the area covered by hummocky moraine deposits, the till is from 12 to 45 meters thick. The areas of ground moraine south of Joseph Lake and surrounding Beaverhill Lake are generally covered by till which is less than 12 meters thick (Bayrock, 1969). There are more recent lake and slough deposits surrounding some of the lakes.

The tills of the area reflect the characteristic bedrock of the area (Bayrock, 1962). They are fairly fine grained, composed of mixed clay, silt and sand with pebbles and boulders as well as lenses of sand, gravel and local bedrock. There are approximately equal amounts of sand, silt and clay with less than ten per cent gravel (Bayrock, 1969).

There are also erratics contained in the till of two major origins. Gravels probably originated in the Rocky Mountains arriving in the area by stream action, while erratics of Precambrian rock were probably brought in from the Precambrian shield by glacial action (Bowser, et. al., 1962).

2.4 Topography

As mentioned earlier, the Cooking Lake Moraine is topographically distinct from the ground moraine surrounding it. Areas to the south and east of the Miquelon Lakes are over 792 meters above sea level. There is a northward slope toward Cooking Lake of approximately 2 meters per kilometer (Canada Topographic Map Series, 1:250,000, sheet 83H).

Locally, the upland topography exhibits clearly the features of a hummocky disintegration moraine. Gravenor and Kupsch (1959) describe hummock disintegration moraine as having knob and kettle topography. These features are deposited by stagnant ice and show no trends which would indicate any sort of live ice deposition. A description of the formation processes of hummocky disintegration moraine is given by Gravenor, Green and Godfrey (1960) in Air Photographs of Alberta.

In addition to knobs and kettles, the area also exhibits other features characteristic of disintegration moraine such as moraine plateaus and till ridges. In the Cooking Lake moraine the knobs and hillocks are circular to oval in outline. The average height is 4.5 meters, however some may be found up to 15 meters in height. Till ridges tend to be short in length. Moraine plateaus are covered with glaciolacustrine materials, probably deposited in supraglacial lakes (Bayrock and Hughes, 1962). The depressions in the moraine tend to be filled with water with the major lakes in the area (Cooking, Hastings, Ministik, Joseph, Oliver, etc.) filling the larger depressions. An illustration of the knob and kettle topography is presented by air photographs, especially those flown on August 9, 1973 for the Department of Environment for the land use study of the moraine (AS 1250, NTS 83H6 Line 7, photos 97, 98 and 99; NTS 83H7, Line 9, photos 153, 154 and 155).

In many parts of the moraine, topography is a major determinant of land use. The Canada Land Inventory Soil Classification for Agriculture shows much of the area south of Hastings Lake as having severe limitations to annual field crops mainly due to the topography (ARDA - Soil Capability for Agriculture - Map 83H, 1967). Topography is listed

as a limiting factor when "Either steepness or the pattern of slopes limits agricultural use." In the Soil Survey of the Edmonton Sheet (Bowser, et. al., 1962), much of the moraine area is shown as having "rolling" topography (Maps accompanying Soil Survey of the Edmonton Sheet). This designation is given to areas having 10 to 15 per cent slopes. In most cases these slopes are rounded both at the crests and bases of slopes. Because of this there are numerous depressions and upland areas with very little or no slope.

The area has a general slope from south to north. Because of the well rounded knobs, however, there are many south facing slopes in the area as well.

2.5 Drainage

As mentioned earlier, the actual hummocky disintegration moraine is higher than the surrounding area, so drainage is away from it in all directions. To the east drainage is mainly through Katchemut and Hastings Creeks toward Beaverhill Lake, then north into the North Saskatchewan River in Beaverhill Creek (Figure 1). In most years, however, there is no drainage from Beaverhill Lake since evaporation exceeds inflow and precipitation.

In the south of the study area, drainage from the Miquelon Lakes tends toward Camrose Creek and on into the Battle River system which is tributary to the North Saskatchewan near Battleford, Saskatchewan. It was thought that when Miquelon Lake was at a higher level that it formed part of the chain of drainage with the other lakes of the moraine (Nyland 1969, 1970). It seems now, however, that when there has been outflow from the Miquelon Lakes it has always been to the south.

Toward the west drainage is through several small creeks such as

Clearwater and Irvine into Blackmud Creek. Blackmud Creek flows into Whitemud Creek which joins the North Saskatchewan in southwest Edmonton.

In the north of the study area drainage is through Ross, Astotin and Pointe aux Pins Creeks into the North Saskatchewan downstream from Edmonton.

The nature of the hummocky disintegration moraine results in disorganized drainage in most of the area. With the domination of the topography by knobs and kettles and small regional surpluses in most years, very few large drainage channels have become established. Only Hastings Creek flows to any extent within the boundaries of the moraine and its flow is best described as intermittent. A great amount of runoff is overland in nature in a large number of very small channels rather than consolidated into major channels. Much of this runoff into "dead" basins or small lakes and sloughs which have no outflow in most years. These small lakes and sloughs reduce the amount of water available to the major lakes of the moraine. In years of average or below average precipitation, they do not contribute runoff to the major lakes, thereby effectively reducing the size of the drainage basin. This case is discussed by Stichling and Blackwell (1957) and Laycock (1959 and 1967).

In many areas of the moraine, artificial drainage has been established. In order to intensify farming, many farmers have initiated ditching and drainage of sloughs. This practice is evident, especially in the Hastings Lake basin, north of the lake, and its effect on the water balance of the area will be discussed in Chapters V and VI.

One area of moraine history under question is post glacial

drainage. These patterns will be discussed in Chapter III.

2.6 Soils

The soils of the Edmonton sheet (83H) were surveyed and reported on in 1962 by Bowser, Kjearsgaard, Peters and Wells for the Alberta Soil Survey and the Canada Department of Agriculture (Figure 4).

The parent material for the soils comes from the tills and other glacial deposits which are derived from the Edmonton Formation bedrock (Bayrock and Hughes, 1962). The tills are generally of a clay loam texture with low permeability.

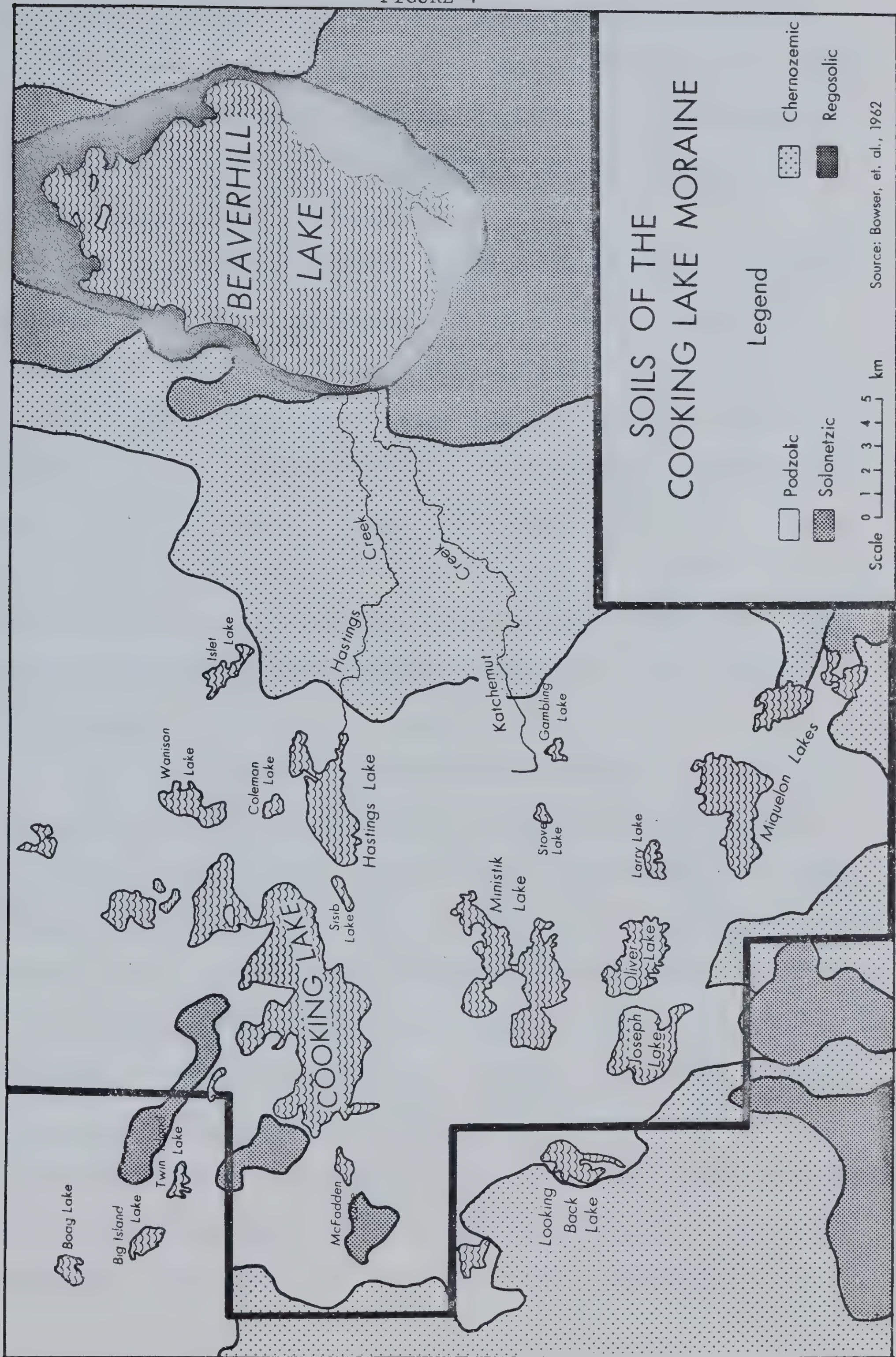
The soils of the Cooking Lake moraine are generally of the Podzolic order. They are described as being "well and imperfectly drained soils, developed under forest" (Bowser, et. al., 1962). Within the order of Podzolic soils comes the great soil group "Grey Wooded Soils" which is the main soil group of the area. Grey Wooded Soils develop mainly under forest cover with a high degree of organic material present.

Within the Grey Wooded great soil group, twelve series have been identified. The major series found in the study area is Cooking Lake loam. It is described as being a well drained, orthic Grey Wooded soil (Bowser, et. al., 1962). Parent material is glacial till of Edmonton formation origin with stone throughout the profile.

A portion of the Cooking Lake moraine study area is covered by solonetzic soils. They are found mainly to the south and east of the Joseph Lake area and on the eastern edge of the hummocky moraine and are widespread in the flatter plains to the east.

On the eastern edge of the study area, surrounding Beaverhill Lake, Chernozemic soils were developed on till plain. It is probable

FIGURE 4


SOILS OF THE
COOKING LAKE MORAINE
Legend
Podzolic
Solonetzic
Chernozemic
Regosolic
Scale 0 1 2 3 4 5 km
Source: Bowser, et. al., 1962
BEAVERHILL
LAKE
Hastings Creek
Katchemut Creek
Islet Lake
Wanisan Lake
Coleman Lake
Hastings Lake
Gambling Lake
Stove Lake
Larry Lake
Miquelon Lakes
Ministik Lake
Sisib Lake
COOKING LAKE
Oliver Lake
Joseph Lake
Twin Lake
Big Island Lake
Boag Lake
McFadden
Looking Back Lake

that the entire area was once covered by Chernozemic soils. They developed under grassland vegetation. More recently, with more humid conditions, forest vegetation became established, the soils became more podsolized and changed from black to the Grey Wooded soils now present (Bowser, et. al., 1962).

Much of the moraine area is listed by the Canada Land Inventory as having restrictions on agriculture use of the area because of soil limitations. These limitations may be due to undesirable structure, low permeability, restricted rooting zone, low fertility or moisture holding capacity or salinity (ARDA - Soil Capability for Agriculture, Map 83H, 1967). Bowser, et. al. (1962) describe the use of Grey Wooded soils in this manner: "If on fairly level topography it is satisfactory for growth of hays, coarse grains and legume seed: If on very rough topography it should be left in its native state."

2.7 Climate

The climate of Alberta was discussed by Longley in two publications (1968, 1972). For the study area a number of meteorological stations' data were used to supplement the data presented by Longley and in the Atlas of Alberta (1969, pp. 13-19) to determine the climate of the area. For long term climatological data, records from the Edmonton Industrial Airport were used. Observations for the station are relatively complete from 1880 to the present. The airport is located approximately 4.8 kilometers northwest of the center of Edmonton at an elevation of 670 meters above sea level. The airport has been located at this site since 1937. Prior to this time observations were made at several sites nearer the city center, all at approximately the same elevation.

Since the early 1950's the urban heat island has had a noticeable effect on temperatures. To counteract this problem, data from the Edmonton International airport is used for recent water balance calculations. International airport data more closely approximate the conditions present in the moraine with respect to temperature and precipitation amounts. Observations began at the International airport in November, 1960.

The airport is located on level ground approximately 24 kilometers south of the city of Edmonton and 38 kilometers west of the center of the Cooking Lake moraine. The official elevation of the airport is 723 meters above sea level.

In addition to data from the Edmonton Industrial and International airports, climatological data from Edmonton Namao airport (military) and the towns of Camrose and Vegreville were used to provide a better regional range of information (Appendix I). The most notable difference in the data used is the decrease in precipitation from west to east (45.90 cm average for International, 38.67 at Vegreville, 43.37 cm at Camrose). The patterns of average precipitation are represented on a series of maps prepared by Pat Cary for Dr. A. H. Laycock in conjunction with the Cooking Lake area Study (Laycock, 1975). It is felt that due to the slightly higher elevation, precipitation amounts of the Cooking Lake Moraine closely approximate those of the Edmonton International Airport.

January is the coldest month with respect to mean monthly temperature averaging -16.3°C. July is the warmest month with a mean of 16.1°C (Edmonton Annual Met. Summary - International Airport).

The frost free period at the Industrial airport averages approxi-

mately 110 days (Longley, 1972, Atlas of Alberta, 1969) with extremes of from 50 to 174 days (1975). The frost free period averages much less at the International airport, away from the urban heat island. An example of the difference is 1974. At the Industrial airport the frost free period was 147 days compared with 94 days at the International airport. The slightly greater elevation of the latter may also be a factor in its lower temperatures.

Precipitation averages 45.90 centimeters at the International airport (Standard Deviation = 17.8 cm). Average annual rainfall is 33.81 centimeters while annual snowfall is 131.2 centimeters. On the average 34.27 centimeters of the annual precipitation total falls during the April through September growing season. This amounts to 74.6 per cent of the average annual precipitation.

The average annual duration of sunshine is 2345.9 hours. This is just over 50% of the amount possible. The average annual growing degree days value is 2280. The May to September average is 2197 (Edmonton Meteorological Summary, International airport, 1974).

The Edmonton International airport receives predominantly southerly winds in most months. The exceptions are the months of June, July, August and September when the main wind directions are north and northwest. The average annual wind speed is 14 kilometers per hour. The windiest month is April with a monthly average of 17.2 kilometers per hour (Atlas of Alberta, 1969, Edmonton Meteorological Summary - International Airport, 1974).

2.8 Vegetation

The natural vegetation of the study area is typically aspen parkland (Bird and Bird, 1967, Atlas of Alberta, 1969, pp. 28-29). In

areas outside the actual disintegration moraine, grass vegetation is dominant. Moss (1955) describes this as the rough fescue association. This association is characterized by the dominant grass, *Festuca scabrella*.

In the actual moraine area, forest cover is present except where it has been cleared by man. Moss describes a poplar association and a balsam poplar association. The poplar association with its main tree type, aspen (*Populus tremuloides*), is found under a wide range of conditions. These range from well drained higher locations to areas near the shores of water bodies where they are, in part, phreatophytic. More will be said concerning this state later (Chapters V and VI). Balsam poplar (*P. balsamifera*), the main tree of the balsam association, are generally found in more moist situations such as north facing slopes and in poorly drained sites. The balsam association is much less widely present in the study area. According to Moss, there are five layers of growth in the poplar and balsam associations. The highest includes the major, fully developed trees. The second layer includes lower trees and higher shrubs. The third layer includes shrubs and the lower two layers are respectively herbs and mosses. In the poplar association, the first (upper) layer consists of aspen trees. The shrubs found exclusively in the poplar association include snowberry (*Symphoricarpos albus*), Saskatoon berry (*Amelanchier alnifolia*) and buffalo berry (*Shepherdia canadensis*). Herbs characteristic of the association are bunch berry (*Cornus canadensis*), and wild lily-of-the-valley (*Maianthemum canadense*).

The balsam association begins with the main tree, balsam poplar. The shrubs include red osier dogwood (*Cornus stolonifera*), honeysuckle

(*Lorniser involucrata*) and several types of berries (*Ribes* spp.). The herbs common to this association are bluebells (*Mertensia paniculata*), horsetail (*Equisetum* spp.) and palm leafed colt's foot (*Petasites palmatus*).

There are several species common to both associations. Most prominent are shrubs and small trees including willows (*Salix* spp.), wild rose (*Rosa woodsii*), prickly rose (*R. acicularis*), low bush cranberry (*Viburnum edule*) and raspberry (*Rubus idaeus*).

Poplar stands are usually found in even aged stands since they start regrowth easily after burning. There are tendencies toward a natural succession from poplar to spruce (Moss, 1955). The young spruce grow more slowly, but as the poplars thin with advancing age, spruce takes over. Fire, however, plays a major role in altering this succession. Fire is only a minor setback to the poplar and regrowth is quick and vigorous. To spruce, though, it is devastating and regrowth is slow and often choked out by poplar growth.

Poplar stands are most evident in the Cooking Lake moraine due to the widespread burning in the late 1800's. There are some evidences, however, of the natural spruce succession, most notably Koney Island in Cooking Lake which was protected from the fires of the late 1800's.

2.9 The Water Balance

For many years the net inflow of water into and outflow of water from areas on the earth's surface have been studied. A number of different empirical formulas have been developed. Most of these concern the determination of water use. For a proper perspective for a study of this type, a discussion of some of the different methods of estimation of water use follows.

2.9.1 Thornthwaite

In 1948, Thornthwaite described a method for calculating evapotranspiration which involved using mean monthly temperature and an index factor which was used to represent day length and heating. His procedures were found to be quite valid in continental North America where the formula was developed but did not work well in other areas such as Western Europe where temperatures are anomalous for their station latitude (Ward, 1967, Chang, 1968). There the transfer of advected heat caused greater amounts of evapotranspiration than could be accounted for by the index factors.

In major studies using data from across Canada (Sanderson and Phillips, 1967) and from the Prairie Provinces (Laycock, 1967), Thornthwaite techniques were found to give an accurate estimate of surplus and deficiency patterns. Kakela (1969), however, found that in a sub-arctic environment corrections for such things as detention storage and drifting were necessary for accurate correlations between actual and computed volumes of surplus. Thornthwaite techniques have also been used with satisfactory results in studies done in the Edmonton area (Erxleben, 1972, Sharma, 1971). The Thornthwaite procedures have been modified for local use by a number of observers. Not all of the stages of calculation are used by all others, the differences due mainly to local conditions and specific study needs. These procedures are useful in identifying the major seasonal patterns and allowances may then be made for recognized local patterns.

2.9.2 Penman

H. L. Penman (1948) also described a method for calculating potential evapotranspiration. It was a complex equation which involved a

coefficient for the drying power of the air, one for net radiation available for heating and coefficients for vapor pressure and sunlight hours. This need for a large number of variables makes the formula applicable over a wide range of climates; however, data for some of the variables, such as vapor pressure, are not easily available. Other coefficients such as net radiation represent data that are obtained from only a small number of stations. This makes Penman's equation unapplicable to many areas (Gray, 1970).

The Penman method for calculating evapotranspiration has been used in Alberta with much the same results. Verma (1968) found values of P. E. lower than those calculated using Thornthwaite techniques in a study on soil moisture holding capacities in the Edmonton area. In a study done in the Fort McMurray area in northeast Alberta, G. Wiche (1977) also found that the values calculated using Penman's methods were well below those using the Thornthwaite technique which he found to give accurate estimates for the area.

2.9.3 Blaney and Criddle

In a paper for the U. S. Department of Agriculture (1950), H. F. Blaney and W. D. Criddle presented a formula for determining monthly consumptive use. This consumptive use factor is similar to Thornthwaite's potential evapotranspiration factor. Blaney and Criddle's formula involved coefficients representing monthly temperature, monthly percentage of daylight hours of the yearly total, mean monthly relative humidity and a constant for each of a number of different crops (either winter or summer). The coefficient varied due to the differing lengths of growing seasons (ex. - alfalfa greater than cotton).

The values for Blaney and Criddle's formula came from experiments done in Texas and New Mexico and the values for consumptive use tend to be too high when the formula is adapted to northern latitudes because of too great an allowance for day length (Laycock, 1967). It has also been found unsuited to use outside the arid areas of the western United States where it was developed (Chang, 1968, Ward, 1967, Gray, 1970).

2.9.4 Others

Other researchers have conducted studies relating to evapotranspiration and soil moisture (Lowry and Johnson, 1942, Turc, 1953, Budyko, 1958 and 1974). Lowry and Johnson's equation again solves for consumptive use but there is no allowance for day length or soil moisture storage. Turc and Budyko tend to require data that are not easily available at all meteorological stations such as net radiation, vapor pressures and different surface temperatures. Adequate discussions of the different formulas and their applications and limitations can be found in several general hydrology texts (e.g. Ward, 1967, Chang, 1968, Gray, 1970).

The difference between procedures can be significant, but for convenience in application, widespread regional testing and use, adaptation to use with local factors that may be identified (e.g. soil moisture storage) and usefulness in applied studies, the Thornthwaite procedure appears to be most suitable for a study of this type.

2.10 Discussion of the Thornthwaite Equation

C. W. Thornthwaite was one of the first to make an attempt at climatic classification using water balance as the key (Thornthwaite, 1948). From his work the moisture balance for a region can be denoted

by the equation:

$$Ppt = (PE-D) + S \pm St.\ Ch.$$

where

	Ppt	= Precipitation
	PE	= Potential evapotranspiration
	D	= Deficit
	S	= Surplus
and	St. Ch.	= Storage Change

A definition of each of these terms is necessary for a complete understanding of the water balance.

2.10.1 Potential Evapotranspiration

Evapotranspiration is the factor in the water balance which is most affected by other variables. Potential evapotranspiration is described by Thornthwaite and Mather (1955) as "the amount of water which will be lost by a surface completely covered with vegetation if there is sufficient water in the soil at all times for use by vegetation." While this accurately explains transpiration it is unclear about the role of evaporation. According to Young and Blaney (1942, in Ward, 1967), evapotranspiration can be described as "the sum of the volumes of water used by the vegetative growth of a given area in transpiration or building of plant tissue and that evaporated from adjacent soil snow or intercepted precipitation on the area in any specified time."

Evapotranspiration can be measured by a device called an evapotranspirometer which is used to measure the water balance in a small parcel of soil. A description of an evapotranspirometer and its workings can be found in Principles of Hydrology by R. C. Ward (1967). When one is considering a large area, however, it is much more convenient to calculate potential evapotranspiration using meteorological data.

In Alberta, potential evapotranspiration amounts increase generally from west to east and from north to south. Average yearly P.E. in the Edmonton area amounts to slightly over 50 centimeters (Atlas of Alberta, 1969, Laycock, 1975).

2.10.2 Deficit

Deficit occurs in the water balance when the moisture supplies (precipitation or soil moisture) available are inadequate to meet evaporation and transpiration requirements. Plants are able to use a certain amount of water from storage in the soil. This amount varies with several factors including soil type and rooting depth and will be discussed later in this chapter. When potential evapotranspiration exceeds precipitation for a month, soil moisture must be used to meet transpiration requirements. When this reservoir is used up, a moisture deficit results. At this point the amount of actual evapotranspiration (PE-D) that occurs is less than potential evapotranspiration.

At the 10 centimeter storage category, the annual average deficit in the study area amounts to approximately 12.5 centimeters (Atlas of Alberta, 1969, Laycock, 1967 and 1975). From recent data (Laycock, 1975) this figure decreases sharply to less than 10 centimeters just west of the study area. The amounts of yearly deficit can vary annually from 0 in wet years to over 25 centimeters in dry years.

2.10.3 Surplus

A surplus of moisture occurs when soil moisture storage levels are completely recharged and withdrawals due to evapotranspiration are exceeded by precipitation supplies. In nearly all climates there is a period in which precipitation exceeds potential evapotranspiration.

It is during these times that soil moisture is recharged and surpluses occur. In Alberta this is normally during the spring snowmelt season.

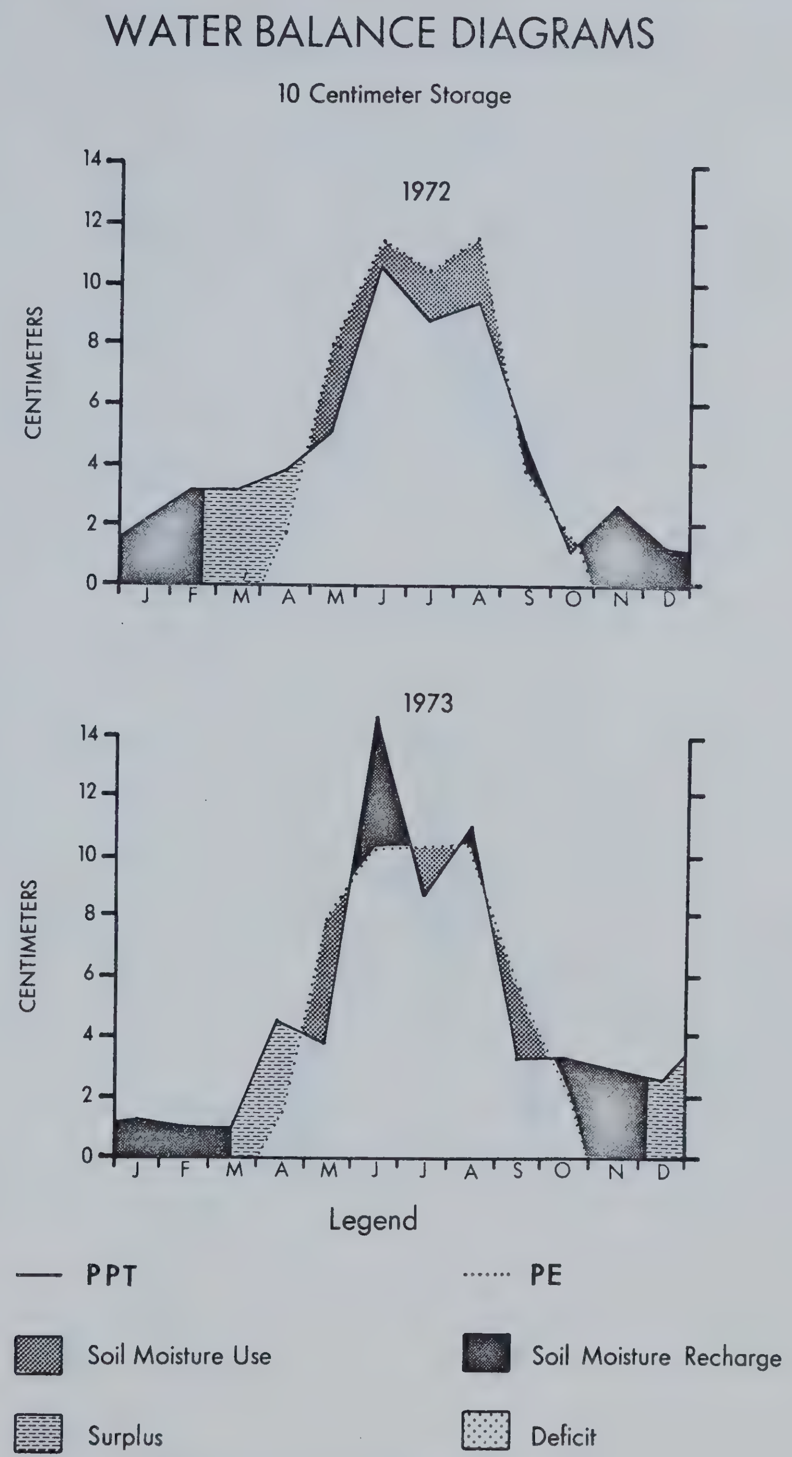
From long term climatic data, at the 10 centimeter storage category, the annual surpluses in the study area average around only 1 centimeter (Atlas of Alberta, 1969, Laycock, 1967 and 1975, Sanderson and Phillips, 1967). In many years there is no surplus at the 10 centimeter storage level; however, in very wet years surpluses of over 12 centimeters have been recorded.

2.10.4 Storage Change

Storage change can be either a positive or negative coefficient. In months during the growing season, when potential evapotranspiration exceeds precipitation, storage change will be negative in that amount until storage is zero. Conversely, when precipitation exceeds potential evapotranspiration, storage change will be positive in that amount until the soil reaches field capacity. For longer periods, usually full years, the storage change is the amount by which moisture in storage at the end of the period is greater or less than that at the beginning of the period. Some of this storage may be in the form of snow, a type of detention storage upon the surface that can be measured for use in the water balance equation.

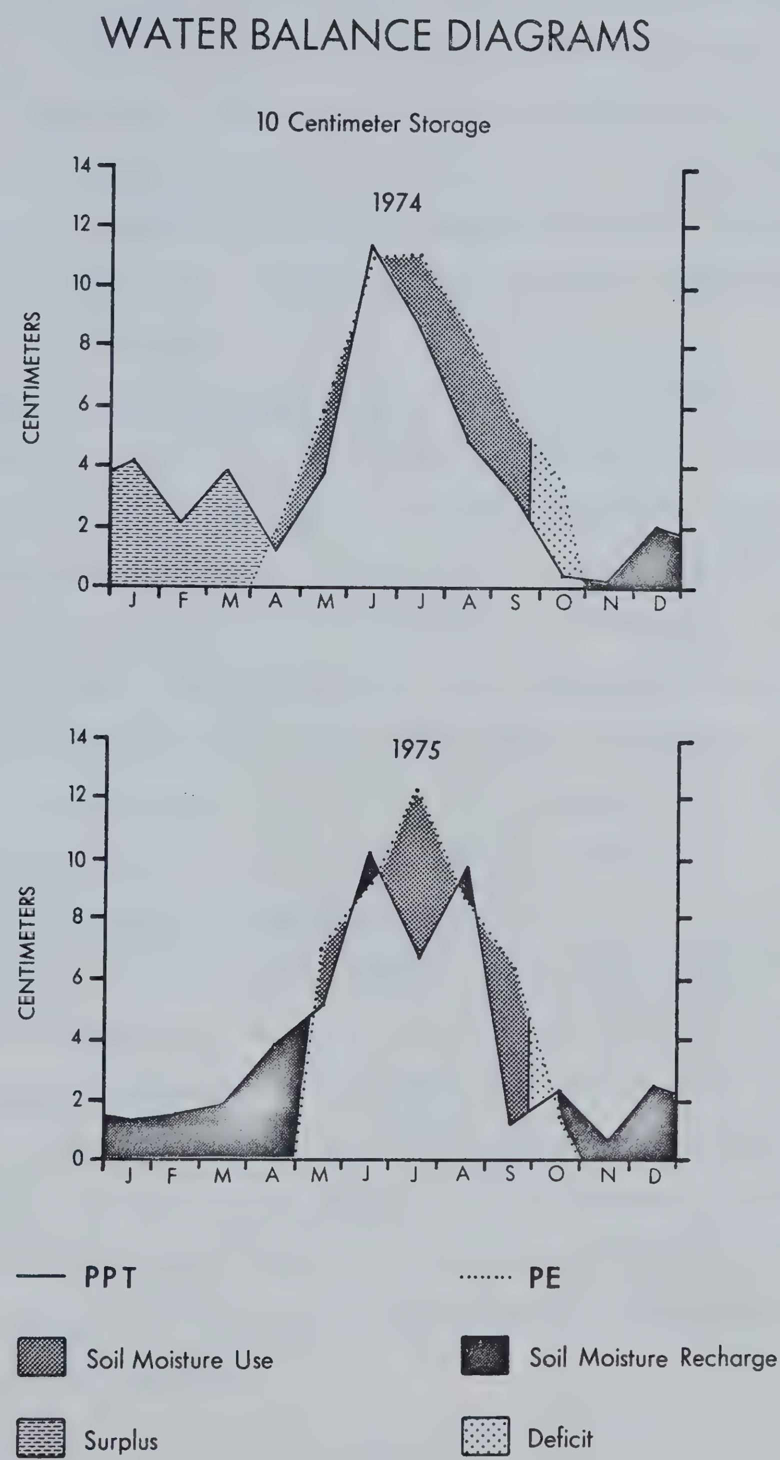
Figure 5 is a graphical representation of four years' water balance of the Edmonton area at the 10 centimeter storage category. These four years are shown to illustrate several features of the Edmonton area water balance. The year 1972 was a near normal year. Snows from the winter of 1971-72 completely recharged soil moisture with some surplus. Soil moisture usage occurred in the summer, but no deficit was experienced. 1973 shows little soil moisture in the summer time

FIGURE 5



based on C. W. Thornthwaite - 1957

FIGURE 5



based on C. W. Thornthwaite - 1957

and complete recharge by December, 1973. This lead to the above normal amount of runoff in the spring of 1974 which caused flooding. The latter half of 1974 was quite dry and winter precipitation was not enough to completely recharge storage capacities. Because of this the 10 centimeter storage level was not completely recharged and runoff volumes were below normal. Another dry summer lead to a soil moisture deficit by late September.

2.11 Effects of Physical Characteristics on the Water Balance

The water balance is made up of several coefficients. Each of these is affected by elements of the physical environment. These include geology, soils, climate and vegetation. In some cases the effect is a direct one such as the effect of precipitation on surplus and deficiency patterns. Some factors have a more indirect effect, such as the permeability of soils and its effect upon the retention of soil moisture. The following is a review of how the physical characteristics of this area may affect its water balance patterns.

2.12 Bedrock Geology and Surficial Materials

Geology is a factor with an indirect effect on the water balance. In areas where bedrock is near the surface, transmissibility and porosity are important factors. In the Cooking Lake moraine, however, where bedrock is covered by up to 45 meters of glacial till, bedrock plays a minor direct role in the water balance. Its major influence is on the surficial materials which reflect the fine grained sediments of the Edmonton formation and in the partial determination of present day slope and relief conditions.

Surficial materials play a major role in determining the rates of infiltration of water into the ground and percolation through it, thus

directly affecting runoff. Infiltration into fine grained materials occurs at a much slower rate than in more porous soils. Musgrave and Holtan (in Chow, 1964) state that storms which occur on areas with a soil composed of mainly silt and clay cause processes which severely impede infiltration. They describe a process by which raindrops break down soil which causes small particles of silt and clay to float across the soil surface and clog previously existing pores, thus severely reducing infiltration. Although the occurrence of high intensity rainfalls is not frequent, this situation could still cause a problem where vegetative cover has been removed. In fine grained soils, there is a tendency toward swelling. In the soils of the area which are composed in part of bentonitic clays from the Edmonton formation, swelling is a major problem. This process is more evident in hindering infiltration during moderate intensity storms of longer duration.

2.13 Soils

Soils play a major role in the water balance of a region. The effects are both direct and indirect. Cole and Machno (1969) describe the soil as a giant water reservoir system, but they also point up its weaknesses as a reservoir system such as losses by evaporation and transpiration as well as variation in retention and flow within the profile. Colman (1948) used a table in which the moisture holding capacities of various soils (classified by grain size) were documented. They were as follows:

(in inches of water per foot of soil depth)

Soil Type	Pore Saturation	Field Capacity	Wilting Point
Sand	5.0	0.9	0.4
Sandy Loam	5.0	1.8	0.7
Loam	5.0	2.7	1.1
Clay Loam	5.4	3.4	1.7
Clay	5.4	5.0	2.5

The difference between pore saturation and field capacity is referred to as detention storage. It is referred to as detention storage because the soil cannot hold that amount of water indefinitely against the pull of gravity. The time of detention may vary from a few minutes in sand to several days for clay. The difference between field capacity and wilting point is referred to as retention storage which is the amount of water available to plants that soil can hold against the pull of gravity (Storey, Hobba and Rosa, 1964). Some detention storage may be available to plants if wetting periods are frequent.

Verma (1968) described the same conditions for soils of the Edmonton area. He describes the main soil type of the moraine area, Cooking Lake loam, as having average to low infiltration rates with better infiltration with grass than with crop cover. Moisture holding capacities of Cooking Lake loam were found to be (in./4 feet of soil depth):

	Field Capacity	Available Water Capacity	Permanent Wilting Point
2 sample	18.2	9.4	2.1
sites)	22.9	12.5	2.6

If the figures arrived at by Verma are divided (by 4) to the same units as Colman, the values for Cooking Lake loam closely approximate Colman's values for clay loam. The slight difference could be due to some extra detention storage.

Another effect of soils upon water is their effect on infiltration

and transmissivity. Root systems tend to loosen the soil, thus making it more porous and susceptible to moisture infiltration. In forest areas, where leaf litter covers the ground, infiltration rates are greatly increased due to the loose surface. According to Penman (1963), studies done in Russia show infiltration rates of 7:1 in favor of forest over open steppe. Other Russian studies mentioned by Penman show the absorption of forest soil with litter to be three times greater than the same soils without litter. Schiff and Dreibelbis (1950) studied the movement of water in soil. They found that transmission rates in topsoil vary from 20 inches per hour in cultivated areas to a possible 40 inches per hour in forest soils.

Toogood (1963) studied the problem of soil erosion in Alberta and found that the problem was not extreme. He did suggest, however, that runoff be minimized in all ways possible, not so much to prevent erosion but to prevent the loss of valuable moisture, as runoff in areas where moisture deficiency is a limiting factor to crop growth.

2.14 Climate

Climatic effects on the water balance are the most visible of all physical effects on the water balance. It is the common denominator in all coefficients of the water balance.

The climate of the Edmonton area, according to the Thornthwaite classification is "Warm Microthermal." This classification means that annual potential evapotranspiration totals between 42.7 and 57.0 centimeters (Thornthwaite, 1948). During most of the growing season (April - September) potential evapotranspiration exceeds precipitation. It is during this time that soil moisture usage occurs. It is common to experience deficits at the 1.25, 5 and 10 centimeter storage

capacities (and higher capacities if recharge was incomplete) in the mid- and late summer months. Ordinarily these soil moisture storage capacities are recharged in the spring by snowmelt waters. Snow is generally held in a type of detention storage during the winter and is unavailable for soil moisture recharge until the spring thaw.

Exceptions to this pattern occur during unusually wet or dry years. An example of a wet year is 1973 (Figure 5). Summer precipitation was above average and there was little withdrawal from soil moisture storage. Winter precipitation was above average and all soil moisture storage levels were filled. The opposite can be seen in 1974 where the last half of the summer was extremely dry and deficits were experienced. The same case was true for the summer of 1975 and this led to small amounts of surplus in the spring. These cases will be discussed more fully in Chapter V along with a discussion of the effect on spring snowmelt.

2.15 Vegetation

The effect of vegetation on the water balance is the factor which can be controlled to the greatest degree by man to produce changes in the water balance of an area. While he can do little to produce a marked effect on monthly precipitation or temperature, changes in vegetative cover (albedo changes, drifting pattern changes) may have significant effects on surplus and deficiency patterns.

The Thornthwaite water balance makes allowance for soil moisture storage by plants. This is the amount of water in the soil to which they have access and is usually dependent upon depth of rooting and soil type. While Thornthwaite lists several soil moisture values for different plants under different conditions (Thornthwaite, 1955),

Laycock (1967) has described the storage categories which are most applicable to the Prairie Provinces of Canada. These were derived for approximately a clay loam textured soil, but are applicable over a wide range of soil textures except for extremes of sand and clay. They are:

Storage Capacity	Vegetation (Land Use)
1.25 cm (.5")	Roads, streets, bare rock
5 cm (2")	Fallow
10 cm (4")	Arable land (usually cereal grains)
15 cm (6")	Pasture and forage crops (alfalfa, etc.)
25 cm (10")	Mature forest

These storage categories will be defined more specifically in Chapter IV.

It is obvious from this table how the water balance would be affected by a change from forest cover to arable crops. Using Edmonton International Airport data, since 1962 there has been only one year in which there was a surplus at the 25 centimeter storage level (1974), however the 10 centimeter storage level shows a surplus in most years (Appendix I).

Many studies have been made concerning the changes affected by converting a forested catchment area to grass and vice versa (Black, 1968, Hays 1955, Hibbert 1967 and 1969, Johnson and Kovener, 1956, Reinhart and Eschner, 1962, etc.). These and other studies will be discussed in Chapter III.

2.16 Summary

This chapter was an analysis of the physical characteristics of the Cooking Lake moraine and their possible effects on the water balance of the area. The rest of the thesis will be concerned with

determining the effects of land use and yearly snowfall on water balance patterns. Chapter III is an attempt to explain the historical patterns of the water balance. Chapter IV will be an analysis of the land uses and storage categories associated with them and how they might affect surplus patterns. Chapter V will be a survey of the actual surplus patterns in the two years, 1975 and 1976.

The final result of the thesis will be a detailed analysis of the water balance of the Cooking Lake moraine. Special detail will be given to surplus and deficiency patterns in the hope of best using them to maximum efficiency in conserving water and halting declining lake levels.

CHAPTER III

HISTORY

3.1 Early History

The Cooking Lake moraine is a hummocky disintegration moraine created by the Keewatin glacier during the Wisconsin Era (Bayrock, 1962). This glacier advanced over Alberta approximately 40,000 years ago. Glacial retreat was largely by means of stagnation and the ice sheet had left the Edmonton area approximately 12,000 years ago. The Cooking Lake moraine was formed around this time period (12,000 to 14,000 years before present) (Bayrock, 1962).

Following glaciation, the lakes of the moraine formed in the larger depressions. It has been suggested (Nyland, 1969, 1970) that there was once a chain of drainage from Miquelon Lake in the south through Oliver, Ministik, Cooking, Hastings and Beaverhill and then on toward the North Saskatchewan River. As part of a Master of Science thesis in the Department of Geology, University of Alberta, Mr. D. Emerson studied the surficial geology of the Cooking Lake moraine (Emerson, 1977). He suggests that since glaciation there has been no outflow from Oliver and Ministik Lakes toward Cooking Lake. He suggests that in times of outflow these lakes have always drained toward the east through Katchemut Creek. There has been flow from Cooking to Hastings Lake and on toward Beaverhill Lake through Hastings Creek. It is doubtful that Miquelon Lake was ever a part of the chain of drainage of the moraine lakes.

Since glaciation, the climate of the area has been drier than in present times. This is evidenced by the lack of well established

drainage channels in the moraine area. Although there have been cooler and warmer climatic periods, only in the last 400 to 600 years has the climate become noticeably more humid.

3.2 Written History

Written history for the Cooking Lake moraine dates back to approximately 1865 (Nyland 1969, EPEC 1971, ECA, 1970). A report from a traveller through the area showed that Beaverhill Lake was nearly dry in 1865 (Nyland, 1969). The levels of the lakes were brought back up due to heavy rains in the 1870's (Nyland, 1969).

The years from 1880 to 1890 were extremely dry. The years of 1883 and 1889 with 24.07 and 20.72 centimeters of precipitation respectively were the driest in the 96 years that records have been kept in Edmonton (Edmonton Annual Meteorological Summary - 1974). Certainly the gauging procedures were somewhat less exact than now, but the years were undoubtedly dry.

Settlement began during the early 1890's. Soon after the settlers moved into the area they began clearing for agricultural use. In most cases this was accomplished by burning. Many times the fires burned out of control and destroyed many acres of the native spruce forest. The first of these fires occurred in May of 1892 (Nyland, 1969). Clearing fires continued and in 1895 fires destroyed forest in an area from Edmonton east to Beaverhill Lake and from Cooking Lake to Fort Saskatchewan and even north of the North Saskatchewan River (EPEC 1971, Nyland, 1969).

By 1898 the lakes of the moraine were all at low levels and in very poor shape. A topographic map of the area published in May, 1894, showed the lakes at much lower levels. In fact, the present day

Ministik Lake was shown as three separate lakes, Ministic, Atchanis and Kavandish (Topographic map (microfilm), Office of the surveyor, 1894). Conditions for the next five or six years, though, led to a rapid rise in lake levels. The years of 1899 through 1904 all had far above average precipitation amounts (Edmonton Annual Met. Summary, 1974, p. 13). The years 1900 and 1901 had 74.5 and 69.9 centimeters of precipitation respectively. Included in this above average yearly precipitation, these years had above average snowfall which contributed to greater spring runoff.

A factor which has been little mentioned in discussions of the rise of lake levels around the turn of the century has been the effect of deforestation due to clearing and burning. A great deal of research has been done on the effects of deforestation and reforestation on water yield. Most of the work has been done in experimental forests in the United States. E. A. Johnson and J. L. Kovner (1956) showed that by cutting only the understory of forested areas annual streamflow could be increased by as much as 2 area inches in the first few years after cutting. In a 1962 paper, K. G. Reinhart and A. R. Eschner found increases in streamflow of nearly 60% after clearcutting areas of forest in West Virginia. The amount of increase diminished in later years as vegetation was re-established (Reinhart and Eschner, 1962). A. R. Hibbert in a 1969 paper showed streamflow increases of as much as 5.88 area inches after converting a 22 acre site from forest to grass at the Coweeta experimental forest in North Carolina. In an experiment done at the United States Department of Agriculture Northeast Forest Experiment Station, Hornbeck, Pierce and Federer (1970) cleared a forest area and prevented any sort of regrowth by treating the area with herbicides.

The result was an increase of 12.2 area inches with the major portion of the increases coming during low flow months, during which time there would be no losses to transpiration. Any precipitation would go only to replace moisture losses from the soil due to evaporation with the rest showing up as runoff. In an area of reasonably high summertime precipitation, this could account for the major increase in streamflow.

There is some danger in applying the studies mentioned above to areas of central Alberta. These experiments were done in areas which were much more humid than the Edmonton area. While the streamflow increases given by the above studies are certainly valid for the areas they were done in, the same volume of increases noted in some of them (12.2 area inches by Hornbeck, Pierce and Federer, 1970) could not be expected here.

From a 1972 American Water Resources Symposium on Watersheds in Transition come three examples of increased streamflow following deforestation. J. D. Helvey (1972) studied the effects on water yield and stream temperature in a mountain area in central Washington that had been burned over. He found average yield increases of 3.5 inches per year immediately after burning. E. S. Verry (1972) reported a 31% increase in June to October streamflow in the first year after clearcutting an 82 acre site in northern Minnesota. Spring snowmelt amounts were also affected. In the first spring after one-third of the test area had been clearcut, peak flows were 35 per cent lower than had been predicted. This was due to the fact that there was a lag time in peak flows from the uncut area and the spring hydrograph was dual-peaked. The second spring, after cutting, had a peak flow twice that of the expected amount. Clearcutting had been completed at this time.

Finally a study by Lynch, Sopper and Partridge (1972) done in central Pennsylvania showed increases in yield of from 1.2 to 2.9 area inches after clearcutting a 213 acre site. The major increases again were during the low flow period of July, August and September due to decreased transpiration requirements.

Approaching the experiment from the opposite side, Scheider and Ayer (1961) studied the effects of reforestation and found that total yield decreased from .17 to .29 inches annually with peak discharges being reduced 41 per cent each season. Research done by McGuiness and Harrold (1971) at Coshocton, Ohio, shows similar effects of reforestation on total water yield. They show, conversely to Scheider and Ayer (1961), that while reforestation significantly reduced low and intermediate flows, peak flows remained unchanged. This difference in findings from New York to Ohio could be due to the slight difference in climates, but probably relates more directly to precipitation patterns in the specific study years. In another experiment at Coshocton, Ohio Brakensiak and Amerman (1960) found that after changing a plot from agricultural use to woodland there was a loss in annual streamflow of 5.32 inches.

The studies mentioned show the effects of vegetation removal and regrowth on water yield in individual experiments. For an overall view, three texts, Vegetation and Watershed Management by Colman (1953), Vegetation and Hydrology by Penman (1963) and Wildland Watershed Management by Satterlund (1972) are suggested.

Through a combination of factors, lake levels rose significantly during the years from 1900 to 1904. A 1906 topographic map of the area shows the lakes at higher levels than they are at today. Miquelon Lake

was joined instead of being the three separated lakes it is now and Joseph Lake was joined with a slough which is now just north of the lake. With respect to the chain of drainage theory, the 1906 map shows no flow from Miquelon to any of the other lakes of the moraine. It also shows a tributary to Cooking Lake originating somewhere near Ministik Lake, but not from the lake. There is a channel shown between Cooking and Hastings Lakes (topographic map sheet no. 315, microfilm, office of the surveyor general, 1906).

A 1915 topographic map is the first to indicate any sort of drainage chain. It shows flow from Joseph and Larry Lakes into Oliver Lake. From there it goes to Ministik to Cooking to Hastings and finally, to Beaverhill Lake. There is one discrepancy that shows up between these early maps and present day maps. Current maps show a 2500 foot contour surrounding Ministik Lake. The early maps do not show this. Perhaps because of this error in surveying, the drainage from Ministik to Cooking Lake was drawn in because of contours (topographic map no. 315, microfilm, 1915).

In a federal legal survey in 1916, lake levels were still found to be high. Cooking Lake was eight to twelve feet higher than present levels and, ironically, area residents petitioned to have the level lowered (ECA, 1970).

Certainly around this time the lake levels began to decline. Surface water data from 1920-21 showed no flow in Cooking Lake Creek between Cooking Lake and Hastings Lake (Department of Interior - 1920-21). Lake levels became noticeably low around 1930 (Nyland 1969, 1970, EPEC, 1971). This is not evident from topographic maps, probably because little field checking was done before updating each edition.

The first change in lake level after 1909 is shown in 1947 when Beaverhill Lake is shown at a much lower level than normal for 1946.

Several reasons have been suggested to explain the decline in lake levels. In 1927, the town of Camrose built a ditch from the south end of Miquelon Lake to the town to supplement its water supply (ECA, 1970, Nyland 1969, 1970). Nyland puts a great deal of emphasis on this ditch, suggesting it as a major cause of decline in lake levels. This probably had only a minor effect; however, it came at a time when yearly precipitation amounts dropped below normal. It was approximately at this time that Miquelon Lake's levels dropped low enough to form the three lakes now present.

The most probable cause for the drop in lake levels has been related to climatic factors. These climatic patterns have been well documented by Laycock (1973). He attributes the declining levels to drainage area sizes and long term changes in climate (greater deficits in the Thornthwaite water balance since 1931). Annual precipitation has been below normal in a number of years since the mid 1930's. There have been two notable exceptions to that trend since the 1930's. The first is the period of the early 1950's. In the years of 1950 through 1956, with the exception of 1952, precipitation was well above normal (Edmonton Annual Met. Summary, 1974). This was reflected in higher lake levels. All of the lakes exhibited marked rises during this period (Stanley and Associates, 1974). Another exception to the climatic trend has been the period from 1972 to 1974. Again all three years had above average precipitation and the lakes showed corresponding rises, especially in 1974.

Another explanation of the drop in lake levels was put forth by

EPEC Consulting Ltd. in their Economic Analysis of the Cooking and Hastings Lakes in 1971. They suggested that the declining lake levels could be attributed to modern civilization, more specifically the deforestation caused when areas are cleared by settlers. The reasons given are that trees around a body of water lend more shade and thus, less evaporation and higher humidity which also minimizes evaporation loss. In addition they stated that forests induce infiltration of runoff and tend to maintain higher groundwater levels (EPEC, 1971).

While it has been shown that a forest cover does increase the amount of infiltration by precipitation (Kohler, 1944, Ursic and Thames, 1960) it is probable that this water does not reach the groundwater table but goes mainly to recharge the greater soil moisture storage capacities of forest cover areas. The review of deforestation literature has shown that the effect of forest cover removal is to increase surface runoff which would add to the lake levels. In addition, while a forest cover may play a significant role in the reduction of evaporation from a small body of water, in even small drainage basins the increased evapotranspiration of a forest cover more than compensates for the reduction in evaporation. Because of the trees surrounding small water bodies, both surface and groundwater flows toward the water body are reduced.

3.3 Recent History

In recent years the residents of the Cooking Lake moraine have become alarmed over the declining lake levels and have attempted to take action. In the fall of 1970 nearly 600 people signed a petition requesting governmental action in halting the decline of lake levels. The Water Resources Division of the Department of Agriculture verified

the names on the petition and then circulated a questionnaire to a portion of the signers. The questionnaire concerned how the petitioners chose to spend recreation time in the moraine.

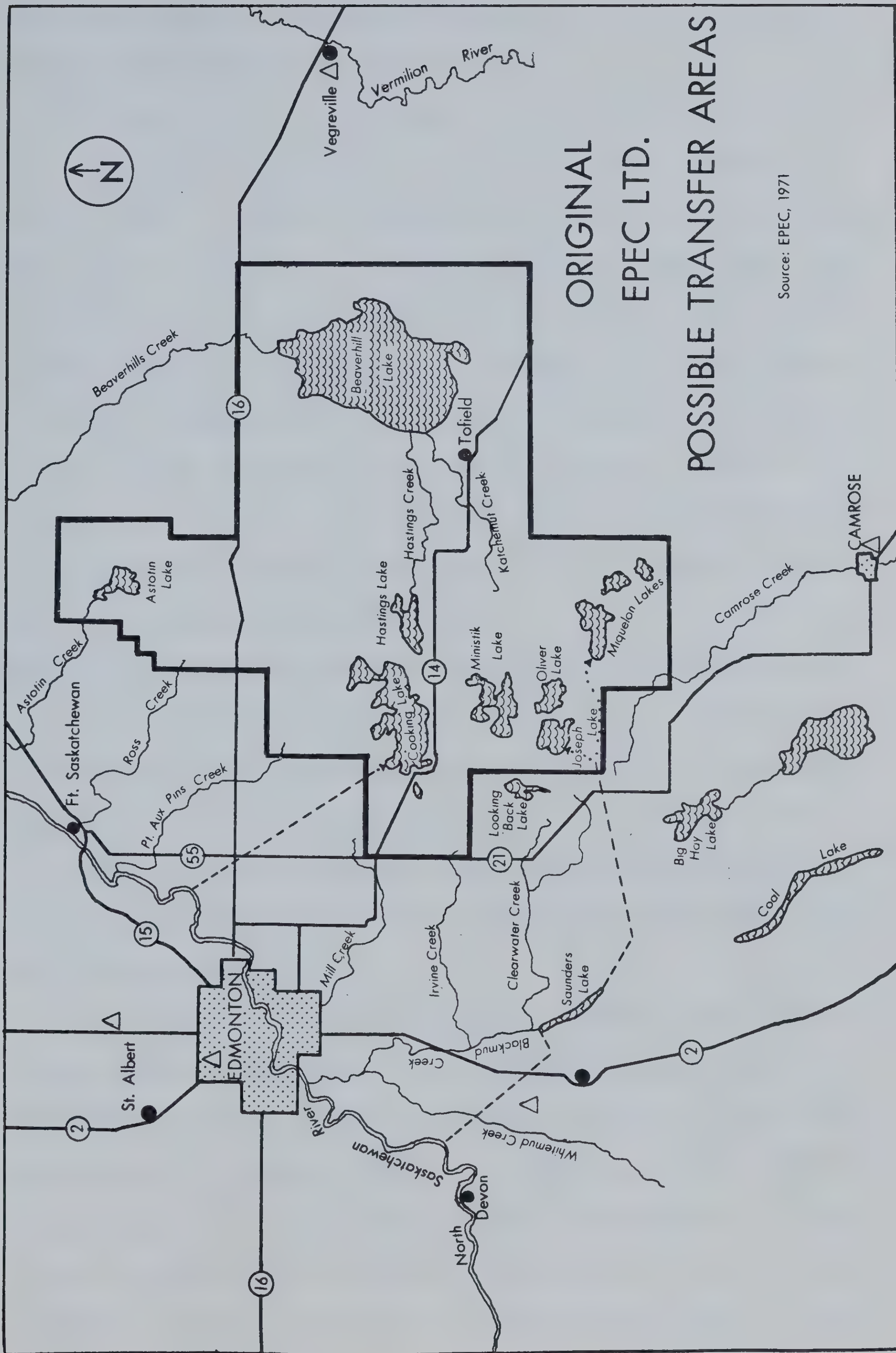
In 1971, EPEC Consulting Ltd. was commissioned by the Department of Environment to do an economic analysis of the Cooking-Hastings Lakes areas. In the report it was suggested that the only reliable way of raising the lake levels was to import water from an external source and the North Saskatchewan River was deemed the nearest perennial source of supply.

Two pipeline routes were suggested at that time. One involved piping water from downstream of Edmonton into the west end of Cooking Lake (Figure 6). This scheme would raise the levels of Cooking and Hastings Lakes only. The second route involved pumping from a point upstream from Edmonton into Joseph Lake. As the levels of Joseph Lake came up it was thought that overflow would occur and as it increased in the succeeding lakes the original chain of drainage would be reestablished. Cost estimates ran to nearly 3.6 million dollars for Scheme B and 2.04 million dollars for Scheme A.

In the initial EPEC report it was estimated that with pumping, the water qualities of the lakes would be improved. At a pumping rate of 30 cubic feet per second, 32 months of pumping would raise the levels of Cooking and Hastings Lakes by six feet. It was felt that the flushing due to the circulation of the water would improve water quality and the lakes would return to their early century quality in approximately five years.

One distinguishing characteristic of the 1971 EPEC report was a lack of suggested water supply alternatives. It was suggested early

FIGURE 6


ORIGINAL
EPEC LTD.
POSSIBLE TRANSFER AREAS
Source: EPEC, 1971
N
Vegreville
Vermilion River
Beaverhills Creek
Beaverhill Lake
Tofield
Hastings Creek
Katchemut Creek
Astotin Lake
Astotin Creek
Hastings Lake
Cooking Lake
Ministik Lake
Oliver Lake
Miquelon Lakes
Joseph Lake
Looking Back Lake
Camrose Creek
CAMROSE
Big Hay Lake
Coal Lake
Ft. Saskatchewan
Ross Creek
Pt. Aux Pins Creek
Mill Creek
Irvine Creek
Clearwater Creek
Saunders Lake
Blackmud Creek
Whitemud Creek
EDMONTON
St. Albert
North Saskatchewan River
Devon
16
14
55
15
21
2

that the only method of water supply that should even be considered was importation from the North Saskatchewan.

In August of 1973, the Environment Conservation Authority held public hearings on the proposal to restore the levels of Cooking and Hastings Lakes. A number of opinions came out at the hearings regarding different aspects of the effects of raising the lake levels. Presentations were made concerning doubts over the cost benefit analysis (LeFrancois, public hearings, p. 46, Pattison, p. 100), questions about the effect of importation on water quality (Rasmussen p. 112, Simpson, p. 92), concern over possible flooding of farmland or cottages (Mullholland p. 38, Eleniak, p. 42, Summary). Some expressed opposition to importation from the North Saskatchewan in favor of other alternatives (Laycock, p. 78, Eleniak, p. 42, Summary) but most of the briefs expressed support for at least one of the two importation schemes, or at least for some sort of lake level supplementation. Following the public hearings, the Environment Conservation Authority recommended expanding the area to be studied from Cooking and Hastings Lakes to the entire Cooking Lake moraine. In addition they recommended restoring and stabilizing the lakes at optimum water levels (ECA, Report and Recommendations, 1972).

In a 1974 publication entitled Cooking Lake Area Study Potential Alternatives for Water Supply, T. V. Mussivand of the Department of Environment suggested alternative methods for raising and stabilizing lake levels and was one of the first to suggest a possible conjunction of purpose with the Dodds-Round Hill (later Camrose-Ryley) coal development to the south of the moraine. This study tended to endorse the possibility of importation because of a now greater demand for water.

After the public hearings, the Department of Environment initiated a study to be undertaken in three phases to determine the ultimate use of the moraine. The first phase was the inventory phase which involved the collection of inventory data on all facets of moraine area use. The first of these reports, the Water Inventory and Demand Draft Report prepared by Stanley Associates Engineering Ltd. was presented in October, 1974. As did most of the earlier reports, the Stanley Report did suggest internal management as a possibility of water supply, but dismissed it as not being a reliable source. The report had many shortcomings, most of which are discussed in a brief prepared by Dr. A. H. Laycock. Also a part of this phase of the moraine study was the report by G. R. Shelly and Associates (1975) concerning outdoor recreation. In their report it was suggested that the main deterrent to water based recreation was not as much water levels as water quality.

As a part of the studies on the Cooking Lake moraine area, a Cooking Lake Area Study Program was created. It included mainly University of Alberta staff members and included studies on all phases of the moraine from water quality to land use management. During the course of the studies a number of contradictions to the initial assumptions made by EPEC (1971) became evident. Most of these came in the area of water quality. It was determined that flushing of the lake waters would not significantly improve water quality. Dr. D. N. Gallup of the Cooking Lake Area Study Program expressed the opinion that even after raising water levels the results would be large sloughs rather than small ones (Gallup, 1975). Also a part of this committee's work were several theses. Some of the topics were the mapping of snow

patterns using Landsat I imagery (Witter, 1976), forecasting lake level fluctuations using a computer model (Crawford, 1976), surficial geology of the moraine (Emerson, 1977) and this study. Later reference will be made to some of these studies.

The second phase of study as outlined by the Department of Environment was the Formulation of Alternatives phase. It was prepared by EPEC Consulting Ltd. and after assessing the inventory studies it presented alternatives for water supply. Two management alternatives were suggested. One involved water importation via pipeline to the Cooking Lake moraine with provisions made to introduce the water separately to each lake. The second alternative featured mainly internal water management possibilities such as snow cover management (EPEC, 1976). Once again the major emphasis was placed on importation of water to stabilize lake levels. The figures concerning the amounts of water necessary to raise lake levels were derived from lake level data which was somewhat incongruous with current levels. Again the internal management scheme was only lightly regarded.

The third phase of the Cooking Lake Moraine Area Study is the Evaluation and Assessment phase in which the suggested alternatives will be reviewed by the Department of Environment and one suggested for action. No governmental recommendations have yet been made. The report should be available to the public near the time of completion of this study.

The author feels that during the entire course of studies on the Cooking Lake moraine, too much emphasis has been placed on the importation of water from the North Saskatchewan River to stabilize lake levels. It is felt that there are viable alternatives which would be

much less costly in terms of supply and better in terms of quality. Some of these alternatives will be presented and discussed in Chapter VI of this thesis.

CHAPTER IV

LAND USE

4.1 Introduction

Land use, as it affects vegetation type, plays a major role in the water balance of a region, especially with respect to surplus and deficiency patterns. Chapter IV is an inventory of the land use patterns on the ten test sites used in the field survey. An attempt will be made to estimate expected patterns of snowmelt runoff with respect to differing land use.

4.2 Land Use

According to C. W. Thornthwaite, evapotranspiration depends on 4 variables:

(1) solar radiation
(2) capacity of the air to remove vapor (i.e., wind speed, etc.)
(3) nature of vegetation, especially albedo, ground cover and depth of rooting
(4) nature of the soil, especially the amount of water available in the root zone (Thornthwaite, 1955, p. 17).

Regarding the thesis study area, factors one and two have been mentioned in a previous chapter (Chapter II, Section 2.7) and will be discussed more fully in Chapter V, Section 5.2 as to how they affect snow melting. These are meteorological factors and remain relatively constant over the entire study area. The nature of the soil has been discussed previously as well (Chapter II, Section 2.6) and while there is some local variation, the differences in terms of available moisture supply may be considered to be slight.

If ground cover and rooting depth are similar the amount of evapotranspiration as affected by vegetation will differ mainly with changes in albedo and the extent of ground cover. As rooting depth

changes, however, the effect of vegetation on the overall water balance becomes marked. Rooting depth of vegetation together with the soil moisture holding capacity of the soil determines this soil moisture storage capacity. This greatly affects an area's surplus and deficiency patterns. For this reason the determination of land use and vegetation type plays an important role in a study of this sort.

As mentioned in a previous chapter (Chapter I, Section 1.2), selection of the test plots was made with respect to representative land uses. Determination of land use for the test plots came from an air photo mosaic prepared by Jack O. Park for the Alberta Department of Environment. Land use was mapped according to a modified Canada Land Inventory Classification System. The system provides for accurate mapping of a variety of different land uses. The following is a description of the land use categories which will be mentioned in describing the test plots. Included in the discussion will be a mention of the probable soil moisture storage capacities associated with each land use category.

(1) Arable - Land used primarily for cash crops, usually in rotation, but including both cash and feed grains. In this area the usual cash crops are cereal grains (wheat, oats and barley). Also, associated fallow land and land in the process of being cleared for cultivation are included. Several soil moisture storage categories are included in this land use. Fallow land is usually considered to have a 5 centimeter storage capacity. The cereal grains have a capacity of 10 centimeters while land recently cleared for cultivation has a moisture storage capacity of 15 centimeters.

(2) Improved pasture - Land used primarily for the production of

improved pasture, hay and other forage crops. Cultivation and planting may have occurred in a recent year. The usual soil moisture storage category for this classification is 15 centimeters.

(3) Unimproved (Rough) Pasture - Open grassland and scrub grassland primarily, whether used for this purpose or not. If the land is closely grazed a 10 centimeter storage capacity is appropriate. If not, 15 centimeters is used.

(4) Woodland - productive - land bearing forest with over 30 per cent crown cover and 20 feet in height, plus artificially restocked and planted areas regardless of age. Woodland areas of this type are considered to have a soil moisture storage capacity of 25 centimeters.

(5) Wetlands - open wetlands except those showing signs of haying in drier years. The soil moisture capacities for this category could vary, but were generally considered to be 15 centimeters.

(6) Water surfaces - excluding temporarily flooded hay meadows. This category has no moisture limit.

In addition to the above mentioned storage categories a 1.25 centimeter storage capacity should be included. It would include roadways, railroad tracks, trails and rooftops, all areas of low storage capacity. In addition, rural housing units were often listed under the category of rough pasture. In that case, the soil moisture storage value would be 5 centimeters.

Table 1 is an inventory of the individual land uses of each test plot. These data were taken directly from the air photo mosaics. The area of each different plot as well as the individual land uses was determined using a calculating planimeter which was made available for use by the Alberta Remote Sensing Center. Use of this machine saved

TABLE 1

LAND USE OF TEST SUB-BASINS

Test Plot	Location	Size in Hectares	Land Use	Size in Hectares	% of Total Area
1	North of Cooking Lake	107.3	Arable	20.4	20
			Rough Pasture	5.6	5
			Woodland	23.0	21
			Wetland	28.4	28
			Water	29.9	26
2	North of Hastings Lake	280.1	Arable	6.3	2
			Improved Pasture	104.0	37
			Rough Pasture	92.0	33
			Woodland	77.8	28
3	N.E. Corner of Hastings Lake	54.6	Arable	16.2	30
			Improved Pasture	6.9	13
			Woodland	27.8	51
			Water	3.7	6
4	Cooking Lake Creek	107.5	Improved Pasture	83.8	78
			Rough Pasture	14.9	14
			Woodland	8.8	8
5	Sisib to Hastings	148.9	Arable	36.2	24
			Rough Pasture	48.7	33
			Woodland	10.0	7
			Wetland	32.5	22
			Water	21.5	14
6	West Hastings	57.0	Arable	22.5	39
			Improved Pasture	23.2	41
			Rough Pasture	1.7	3
			Woodland	9.6	17
7	Highway 14	55.6	Improved Pasture	14.2	26
			Rough Pasture	21.1	38
			Woodland	20.3	36
8	North of Joseph Lake	29.6	Arable	5.9	20
			Improved Pasture	12.8	43
			Woodland	10.9	37

TABLE 1

(continued)

Test Plot	Location	Size in Hectares	Land Use	Size in Hectares	% of Total Area
9	West of Joseph Lake	284.3	Arable	153.5	54
			Improved Pasture	56.9	20
			Rough Pasture	34.1	12
			Woodland	39.8	14
10	South of Joseph Lake	59.9	Arable	36.8	62
			Improved Pasture	18.7	31
			Rough Pasture	4.4	7

a great deal of time and provided accuracy which would have been difficult to obtain using other means.

It should be noted that the data presented in Table 1 were classified as to land use rather than storage capacity. These data for each test plot will be presented in Section 4.4

4.3 Predicting Snowmelt

There are many formulas for predicting the amount of runoff from snowmelt. Most are essentially index approaches and concern predicting flood flows over a large drainage basin. These formulas are concerned mainly with the volume and timing of peak spring snowmelt flows (Linsley, 1943, Rosa, 1956, Chow, 1964, Fletcher and Reynolds, 1972 and several others). Studies of this type are rarely applicable to small drainage basins like those used in this study. In a small drainage basin, measured in hectares rather than square kilometers, local variations in topography play an important role in the timing and volume of snowmelt runoff. While some of these may be accounted for with correction factors, these and other factors may affect total runoff to an extent that use of a large basin runoff formula would cause great errors when applied to a small basin.

In other cases the data required for the more complex formulas (Viessman, 1967, Dunne and Black, 1971, Quick and Pipes, 1972, Riley, Israelson and Eggleston, 1972, and Gray and O'Neill, 1972 and 1973) such as net radiation, latent heat of vaporization and turbulent heat transfer are not easily measured and are therefore not suited to a study of this sort.

One method of estimating snowmelt runoff with reasonable accuracy and requiring a minimum amount of data is by monitoring soil moisture

indices using Thornthwaite procedures. The only data necessary are (1) mean monthly air temperature, (2) monthly precipitation totals, (3) information on the water holding capacity of the soil and (4) necessary conversion and computational tables (in Thornthwaite and Mather, 1957). It involves computing soil moisture storage and deficits using the equation mentioned previously (Chapter II, Section 2.10). The meteorological data used will be from the Edmonton International Airport.

The following listing of the test plot characteristics includes a breakdown of the soil moisture storage categories present on each site. Also included is a calculation of probable runoff for each of the sites using Thornthwaite procedures. As a comparison, data from the three years previous to the field seasons will be included.

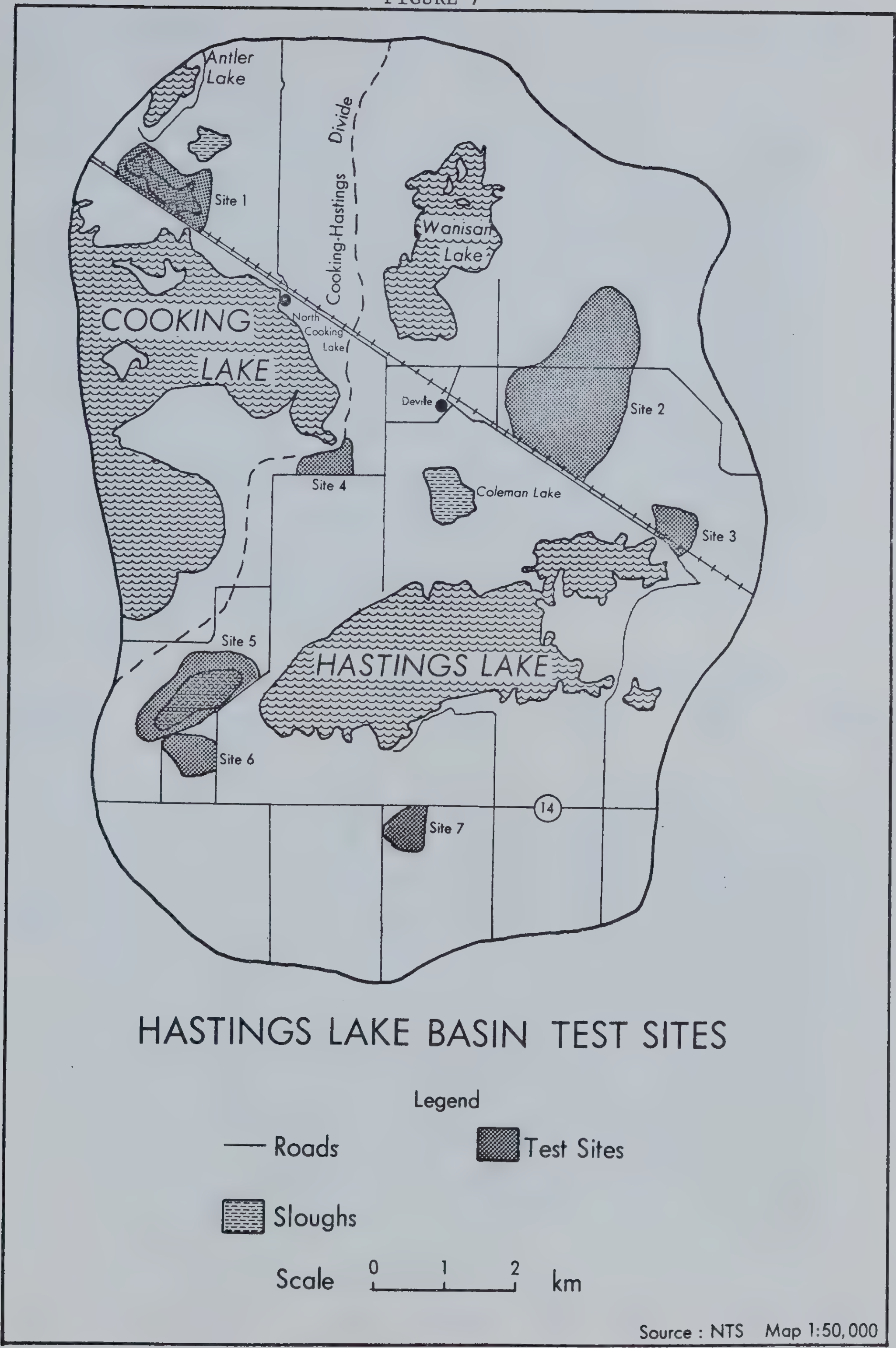
4.4 Test Plot Descriptions

4.4.1 Site 1 - 107.3 Hectares

		Estimated Runoff in Hectare Meters				
Storage	% of Area	1976	1975	1974	1973	1972
1.25 cm	2	.16	.25	4.1	.3	.3
5 cm	-	-	-	-	-	-
10 cm	20	-	-	2.8	.7	1.3
15 cm	29	-	-	4.0	1.0	.3
25 cm	21	-	-	1.6	-	-
Water	28	-	-	-	-	-
Total (HM)		.16	.25	12.5	2.0	1.9
Yield (cm)		.15	.23	11.7	1.9	1.8

Test plot number 1 is located just north of Cooking Lake (Figure 10). It drains through two large culverts under the CN Railroad tracks and was gauged at a 48" culvert under a county road. From the culvert, water drains toward Cooking Lake. The central feature of Plot No. 1 is a large slough (Plate 1). In times of above average precipitation, there is outflow from Antler Lake north of the slough, through the

FIGURE 7



HASTINGS LAKE BASIN TEST SITES

slough to Cooking Lake. The slough is surrounded mainly by woodland with the exception of the northeast shore where there has been some clearing for agricultural use.

Runoff from Site 1 should be less than from many of the other sites in most years due to the large proportion of high soil moisture storage values (woodland and water). It was expected that in both field seasons runoff would be barely measurable with any surplus coming from the low soil moisture storage areas of the road and railroad tracks.

In years of measurable runoff, the early runoff should come from the low storage areas around the railroad tracks. Flow duration would be lengthened due to late melting from the forested areas and the detention storage provided by the water body.

4.4.2 Site 2 - 280.1 Hectares

		Estimated Runoff in Hectare Meters				
Storage	% of Area	1976	1975	1974	1973	1972
1.25 cm	1.0	0.2	.3	.4	.4	.4
5 cm	-	-	-	-	-	-
10 cm	40	-	-	14.4	3.7	6.9
15 cm	31	-	-	11.2	2.9	.9
25 cm	28	-	-	5.6	-	-
Total (HM)		0.2	.3	31.6	7.0	8.2
Yield (cm)		.07	.11	11.3	2.5	2.9

Test plot number 2 is located in the Hastings Lake drainage basin. It has been previously mentioned that there has been an extensive amount of artificial drainage in the Hastings Lake basin. Test plot no. 2 is a site where such drainage has taken place. Much of plot no. 2 (all of the rough pasture - Table 1) was formerly a large slough. In recent years it was drained by ditching and the area now drains through a 152 centimeter culvert under the CN Railroad tracks and an artificially cut channel into Hastings Lake (Plate 2). When there is outflow from

PLATE 1

Site 1 - Looking NE toward Antler Lake drain

PLATE 2

Site 2 - Looking north - Artificial drainage ditch in center

Wanisan Lake, to the northeast, if flows through this subdrainage basin into Hastings Lake.

The large proportion of arable and pasture land is indicative of a high volume of runoff with a somewhat flashy regime in years with surplus precipitation (1972, 1973 and 1974). Runoff might be extended somewhat due to the 28% forest cover of the site. The falling limb of the hydrograph could also be lengthened due to the flows of groundwater and interflow which may be directed toward the old slough.

In both of the field seasons it was expected that runoff would be low in volume coming mainly from the areas of roadway, railroad track and residences.

4.4.3 Site 3 - 54.6 Hectares

		Estimated Runoff in Hectare Meters				
Storage	% of Area	1976	1975	1974	1973	1972
1.25 cm	2	.08	.12	.2	.2	.2
5 cm	-	-	-	-	-	-
10 cm	30	-	-	2.1	.5	1.0
15 cm	13	-	-	.9	.2	.1
25 cm	49	-	-	1.9	-	-
Water	6	-	-	-	-	-
Total (HM)		.08	.12	5.1	.9	1.3
Yield (cm)		.15	.22	9.3	1.6	2.4

Test plot number 3 is located on the north shore of the northeast bay of Hastings Lake. It drains under the CN Railroad tracks and was gauged at a 91 centimeter culvert which runs under the section road.

As with test plot no. 1, the main feature of test plot no. 3 is a slough in the approximate center of the plot (Plate 3). It is surrounded mainly by woodland except for an area on the north side of the slough which has been cleared for agriculture.

The total volume of runoff in years with surplus should be small

PLATE 3

Site 3 - Slough at sub-basin 3

PLATE 4

Site 4 - Low lying marshy area

due to the extent of wooded area and the slough. Initial runoff should begin early from the areas of low soil moisture storage along the tracks and from the road. Duration of flow should be extended by the late melting from the wooded areas and the detention storage by the slough.

In both field seasons it was expected that although runoff amounts would be small, the average runoff amounts might be high compared with the other basins. The road and railroad tracks are near the culvert and runoff from them does not enter the slough. This runoff should go directly to channels and should be measured at the culvert.

4.4.4 Site 4 - 107.5 Hectares

		Estimated Runoff in Hectare Meters				
Storage	% of Area	1976	1975	1974	1973	1972
1.25 cm	0.5	.04	.06	.1	.1	.1
5 cm	-	-	-	-	-	-
10 cm	76.5	-	-	9.5	2.4	4.5
15 cm	15	-	-	1.9	.5	.2
25 cm	8	-	-	.6	-	-
Total (HM)		.04	.06	12.1	3.0	4.8
Yield (cm)		.04	.06	11.3	2.8	4.5

During times of high lake levels, Cooking Lake Creek flowed between Cooking and Hastings Lakes. Due to the decline in lake levels there has been no flow between the lakes for over 50 years. Test plot number 4 is gauged at a 152 centimeter culvert under a section road where it crosses what was formerly North Cooking Lake Creek. Since there is no longer any flow between the lakes, runoff is local in origin.

Nearly all of the area has been cleared for use as pasture. The site has fairly good drainage toward the old creek channel, but the channel itself is rather low lying and marshy. The site has a slightly

south facing aspect (Plate 4).

In years where there is surplus at many of the soil moisture storage levels (1972, 1973, 1974) runoff should begin early at this site and taper rapidly. In the field seasons, however, it was expected that the only runoff would come from the roadway and the roadside ditches.

4.4.5 Site 5 - 148.9 Hectares

		Estimated Runoff in Hectare Meters				
Storage	% of Area	1976	1975	1974	1973	1972
1.25 cm	1	.1	.2	.2	.2	.2
5 cm	14	.8	1.0	2.7	1.2	2.3
10 cm	24	-	-	4.6	1.2	2.2
15 cm	39	-	-	7.5	1.9	.6
25 cm	7	-	-	.7	-	-
Water	15	-	-	-	-	-
Total (HM)		.9	1.2	15.7	4.5	5.3
Yield (cm)		.6	.8	10.5	3.0	3.6

Test plot number 5 is located at the west end of Hastings Lake. A large part of test plot no. 5 makes up the drainage basin of Sisib Lake. The lake was much larger than it is presently. Today it is nothing more than a large slough. When outflow occurs, it is toward Hastings Lake through an artificially cut channel which was intended to handle overflow (Plate 5). Gauging was to take place at a 76 centimeter culvert under the section road which runs along the west end of Hastings Lake. Away from the slough and the wetland surrounding it test plot number 5 is fairly well drained toward the slough. It is well drained enough that cereal grains can be grown. According to the Soil Survey of the Edmonton Sheet (Bowser, et. al., 1962), much of the soil of this plot is peaty meadow soil, developed on lacustrine materials. This soil has a high moisture holding capacity.

Partly because of the low level of Sisib Lake, outflow has rarely

PLATE 5

Site 5 - Taken from lower end of culvert
looking down drainage channel to Hastings Lake

PLATE 6

Site 6 - Looking west from drainage ditch
Note clearing pattern.

occurred in recent years. Because of the high moisture holding capacity of the soil and the detention storage, even in single wet years (1972) there would probably be no outflow. After a series of wet years, however, some overflow toward Hastings Lake could be expected. It was this prospect that prompted the choosing of the Sisib Lake basin as a test site.

In both field seasons surpluses would not have been great enough to cause any outflow. Any runoff would have gone only toward Sisib Lake.

4.4.6 Site 6 - 57.0 Hectares

		Estimated Runoff in Hectare Meters				
Storage	% of Area	1976	1975	1974	1973	1972
1.25 cm	2	.1	.1	.2	.1	.1
5 cm	-	-	-	-	-	-
10 cm	39	-	-	2.9	.7	1.4
15 cm	42	-	-	3.1	.8	.3
25 cm	17	-	-	.7	-	-
Total (HM)		.1	.1	6.9	1.6	1.8
Yield (cm)		.2	.2	12.1	2.8	3.2

Test plot number 6 is also located on the west end of Hastings Lake. It is to the south and adjacent to test plot no. 5. Most of the plot is farmland, either crops or pasture. The only woodland is found surrounding the main drainage channel through the field. This plot was gauged at a 61 centimeter culvert which runs under the road that borders the eastern edge of the drainage plot.

Drainage is reasonably good toward a channel which runs through the field (Plate 6). In years with surplus precipitation in the spring (1972, 1973 and 1974), runoff should begin later than some other sites due to a slight north facing aspect. The hydrograph should peak rapidly and tail off rapidly. In years such as the three mentioned,

runoff from Site 6 should be quite high in terms of volume per unit area.

In 1975 and 1976 it was expected that very little of Site 6 would contribute runoff. Only the areas of roadway and a residence would be expected to contribute runoff.

4.4.7 Site 7 - 55.6 Hectares

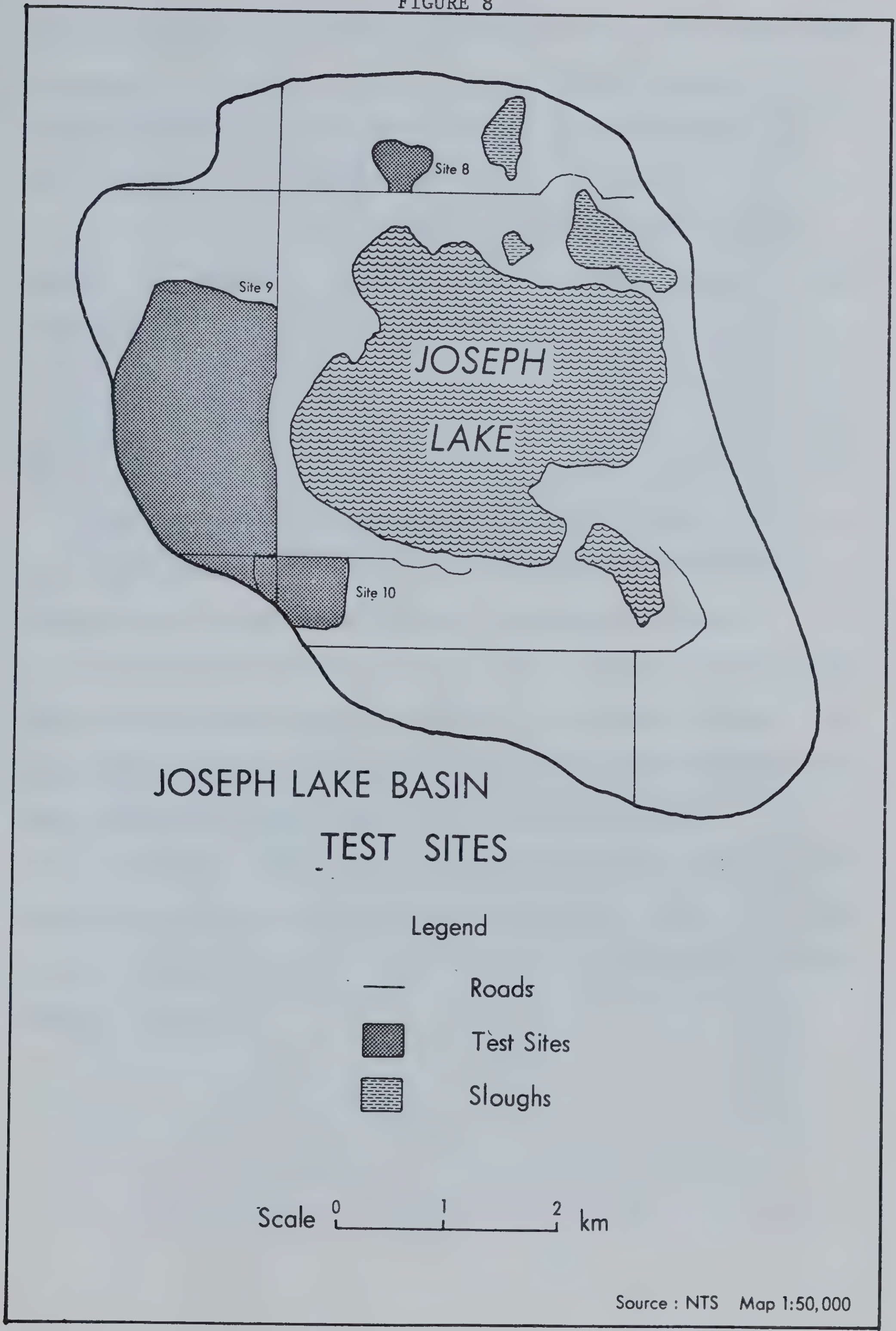
		Estimated Runoff in Hectare Meters				
Storage	% of Area	1976	1975	1974	1973	1972
1.25 cm	0.5	.02	.04	.1	.1	.1
5 cm	-	-	-	-	-	-
10 cm	25	-	-	1.7	.4	.8
15 cm	38	-	-	2.7	.7	.2
25 cm	36.5	-	-	1.2	-	-
Total (HM)		.02	.04	5.7	1.2	1.1
Yield (cm)		.04	.07	10.3	2.2	2.0

Test plot number 7 is located to the south of Hastings Lake. Runoff flows northward toward the lake and was gauged at a 91 centimeter culvert which channels flow under Highway 14.

Test plot number 7 is in an area south of Hastings Lake where relief plays a major role in the timing of the melt. Knob and kettle topography is evident (Plate 7), and much of the woodland area of Site 7 is on north facing slopes. This should delay the start of major melting somewhat.

The land use pattern of Site no. 7, open pasture area surrounded by woodland, is one which is described in many research projects to increase the amount of snowmelt runoff with a favorable lengthened regime (Chapter V, Section 5.15.3). Using Thornthwaite data, very little runoff can be expected from this plot. Measurable runoff should come only from the roadway areas. However, if the land use pattern works as in some of the experiments, allowing increased snow accumulation in

FIGURE 8


Site 8
Site 9
Site 10
JOSEPH
LAKE
JOSEPH LAKE BASIN
TEST SITES
Legend
Roads
Test Sites
Sloughs
Scale
0
1
2
km
Source : NTS Map 1:50,000

the 10 centimeter storage areas surrounded by trees, more runoff could be measured. In addition, some extra runoff could be expected from sloping areas where infiltration capacities may be lessened.

4.4.8 Site 8 - 29.6 Hectares

		Estimated Runoff in Hectare Meters				
Storage	% of Area	1976	1975	1974	1973	1972
1.25 cm	1	.02	.04	.1	.1	.1
5 cm	4	.05	.1	.2	.1	.1
10 cm	30	-	-	1.1	.3	.5
15 cm	28	-	-	1.0	.3	.1
25 cm	37	-	-	.8	-	-
Total (HM)		.07	.14	3.2	.8	.8
Yield (cm)		.25	.5	10.8	2.7	2.7

Test plot number 8 is the smallest plot of the study. It is located in the Joseph Lake basin along the north shore of the lake. It drains under a section road through a 61 centimeter culvert.

Test plot 8 is the location of a small farm, therefore the cropland and pasture have been in production for a number of years. In years with surplus, runoff should begin early and have a high unit volume compared with other basins used in the study (1974).

In the study years much of the runoff should have come from the roadway and the farmhouse and surrounding grounds. Since these areas are near the gauging site, it was felt that the prediction of runoff should be accurate.

PLATE 7

Site 7 - Looking SW - Note clearing pattern

PLATE 8

Site 9 - Looking east toward Joseph Lake from fallow field

4.4.9 Site 9 - 284.3 Hectares

Storage	% of Area	1976	1975	1974	1973	1972
		Estimated Runoff in Hectare Meters				
1.25 cm	1	.2	.3	.5	.4	.4
5 cm	11	1.1	1.5	4.0	1.8	3.5
10 cm	62	-	-	22.6	5.8	10.8
15 cm	12	-	-	4.4	1.1	.4
25 cm	14	-	-	2.3	-	-
Total (HM)		1.3	1.8	33.8	9.1	15.1
Yield (cm)		.5	.6	11.9	3.2	5.3

Test plot number 9 is the largest plot used in the study, located along the western shore of Joseph Lake. It was gauged at a 91 centimeter culvert running under a section road which borders the eastern edge of the test plot.

Over half the test plot is in agricultural production, either as cropland or pasture. Most of this land is on the south of the plot. The only woodland is found on the more poorly drained northern half of the site. Approximately one-half of one quarter section (32.4 Hectares, 80 acres) was lying fallow at the time of field work. The plot is fairly well drained from the south to the culvert location; however, north of the culvert the plot tends to be flatter and more poorly drained.

In a surplus year, total runoff from plot no. 9 should be the greatest in volume of any of the test plots (1974). Initial runoff should come from the fallow field in the south corner (Plate 9) of the plot. It has a slightly north facing aspect, but the low albedo of the bare soil should cause the earliest melting of the test plot. Later runoff will come in turn from crop and pastureland and finally from the forested northern section of the plot.

In the study years, most of the runoff would come from the

farmhouses and adjacent yards and the fallow plot. Some of the runoff from the fallow plot may be lost as overland flow, however.

4.4.10 Site 10 - 59.9 Hectares

Storage	% of Area	Estimated Runoff in Hectare Meters 1976	1975	1974	1973	1972
1.25 cm	2	.1	.1	.2	.1	.2
5 cm	5	.1	.2	.4	.2	.3
10 cm	62	-	-	4.8	1.2	2.3
15 cm	31	-	-	2.4	.6	.2
25 cm	-	-	-	-	-	-
Total (HM)		.2	.3	7.8	2.1	3.0
Yield (cm)		.3	.5	13.0	3.5	5.0

Test plot number 10 is located on the south side of Joseph Lake. It was gauged at a 61 centimeter culvert under a section road which leads to Joseph Lake Park.

Site 10 like the other test plots in the Joseph Lake basin is located outside the actual hummocky disintegration moraine and is therefore more moderate in relief. Plot 10 has a slight north facing aspect and is fairly well drained.

In years of surplus, plot 10 should have the highest per unit volume of all the test basins due to the low storage values present on the plot (1972, 1973 and 1974). While there might be a slight delay in the beginning of runoff due to a slight north facing aspect, the hydrograph in these years should show a flashy regime.

It was expected that plot 10 would show measurable runoff in the field seasons. Some of the area is in the low storage categories (1.25 and 5 cm) and because of the good drainage, most of this should show up as runoff.

4.5 Summary

It should be noted that the runoff patterns discussed in this

chapter are merely expected runoff patterns and not what actually occurred in the dry field seasons. It is important to note, though, that even though there was not enough precipitation to recharge the 10 centimeter storage level, some surpluses could be expected from the areas of low storage such as roadways and railroad tracks. As will be shown in the next chapter, in years of low snowfall, the actual runoff patterns may be greatly affected by drifting, detention storage in water bodies and temperatures during the melt season. The effects of these and several other factors as well as possible modifications to the water balance caused by these factors will be discussed in Chapter V, Section 5.15.

Chapter V will be a discussion of actual runoff patterns. There will also be a discussion of the factors affecting snow melting and runoff.

CHAPTER V

RUNOFF PATTERNS

5.1 Introduction

The previous chapter included a discussion of the individual test plots and their physical characteristics. Also included was a discussion of probable snowmelt runoff patterns using Thornthwaite data, unadjusted for the effects of drifting. This chapter is a discussion of the actual measured runoff patterns. Before they are discussed however, a discussion of the heat transfer processes involved in snowmelt is desirable.

5.2 Factors Involved in Snowmelt

The snowpack in the Edmonton area is a form of surface detention storage. Since there is very little melting during the winter, a buildup of precipitation occurs from the late fall and through the winter months. The spring snowmelt is a quick release for this storage. Conditions during the melt season determine the amount of water which goes to recharge soil moisture storage or goes as runoff. An extended melt period allows gradual thawing of the soil and maximum infiltration. Conversely, a rapid thaw may melt the snow before the ground is unfrozen and most of the snowmelt waters may go as runoff.

In the 1956 U. S. Army Corps of Engineers handbook, Snow Hydrology, most phases of snow hydrology were discussed. Six factors were listed as the major sources of heat energy available to melt snow (U. S. Army, 1956, p. 141). These were

(1) Absorbed solar radiation
(2) Net longwave radiation exchange between the snowpack and its environment
(3) Convective heat transfer (sensible heat) from the air

(4) Latent heat of vaporization released by condensate
(5) Conduction of heat from underlying ground
(6) Heat content of rainwater

All six factors are affected by several variables and should be discussed individually to ascertain all the mechanisms involved in snowmelt.

5.2.1 Absorbed Solar Radiation

Absorbed solar radiation refers to the amount of insolation, both direct and diffuse, received at the surface of the snowpack. In determining the amount of insolation actually received, one must consider the amount of shortwave radiation incident upon the snowpack less the amount of shortwave radiation reflected by the snowpack (albedo). The amount of incident radiation varies according to many factors.

The main factors affecting the amount of solar radiation incident on a surface are solar altitude and daylight duration. On April 21 (snowmelt season) in the Edmonton area the altitude of the sun at solar noon is approximately 49° (from Sellers, 1965, p. 17) and the day length is approximately 14 hours and 24 minutes (from Wilson, 1972, p. 6). The average daily amount of solar insolation on a cloudless day received in Edmonton on April 15 as given by Gray (1970) is approximately 580 langleys (1 langley = 1 calorie of heat energy per square centimeter). This figure seems somewhat high after observing the Monthly Radiation Summary. A more accurate figure would be around 540 langleys. Insolation is usually measured as received on a horizontal surface. However, insolation may vary greatly due to slope and aspect and result in greatly different values with respect to local conditions. Studies done in Eastern Canada (latitude 45°) show that maximum daily insolation at the equinox is greatest on south facing slopes with a gradient

of 40° to 50°, or nearly perpendicular to the sun's rays (Wilson, 1972). It is expected that during the snowmelt season in the Edmonton area, maximum insolation would be received on south facing slopes at an angle of approximately 40°. East or west facing slopes receive insolation varying more with respect to orientation. North facing slopes receive mostly diffuse radiation. Depending on the slope angle, they may receive no direct solar radiation during the melt season at all.

Cloud cover, atmospheric turbidity and atmospheric gasses (CO_2, water vapor and ozone) also deplete solar radiation. Incoming solar radiation may be reflected or absorbed by any of these. It is estimated that as much as one-third of the incoming solar radiation is lost before reaching the earth's surface (Hare and Thomas, 1974).

Forest cover also depletes solar radiation receipt at the ground surface. Studies from Eastern Canada show that under coniferous forest, even in heavily thinned stands, only 9.6 per cent of the amount received in open areas is received at the forest floor (Wilson, 1973 from Vezina and Pech, 1964). Under deciduous cover bare of leaves, the ratio increased to 50 per cent on clear days and 70 per cent on cloudy days of the amount received in open areas.

The total amount of solar radiation converted to heat varies greatly with the reflectivity of the receiving surface (albedo). Different snow surfaces have varying albedos. They range from freshly fallen snow, which can have an albedo as high as 95 per cent (Sellers, 1965, p. 21) but generally averages around 80 per cent (U. S. Army, 1956, Wilson, 1973). A ripe snowpack is usually very granular in texture and its albedo averages approximately 35 to 40 per cent.

During the field seasons of this study, insolation (incoming

shortwave radiation) in the Edmonton area (Stony Plain) averaged 425 lys (langleys) per day in April 1975, 478 lys per day in May 1975, 312 lys per day in March 1976 and 438 lys per day in April 1976 (Monthly Radiation Summary, AES, 1975 and 1976). It should be restated that these figures represent only incident radiation and not net solar insolation.

5.2.2 Net Longwave Radiation

Longwave or terrestrial radiation originates either at the earth's surface or within the atmosphere. In addition to back radiation from the earth's surfaces, longwave radiation is the result of back radiation from three other sources: (1) the earth's atmosphere, (2) cloud cover and (3) vegetative cover (U. S. Army, 1956, p. 156).

Back radiation from the earth's atmosphere comes from all levels. As solar radiation (short wave) is absorbed, much of it is re-emitted as longwave radiation. The amount received at the snowpack depends on temperature and moisture content of the atmosphere. As temperature increases, the amount of radiation increases, therefore the lower 100 meters of the earth's atmosphere has the most significant effect on the amount of longwave radiation received at the earth's surface.

Clouds act as black bodies with respect to longwave radiation. A black body is one which absorbs all of the longwave radiation incident upon it and reradiates at the same wavelength. Under conditions of complete cloud cover the amount of radiation exchange depends on the snow surface temperature and the cloud base temperature difference. When the cloud base temperature is greater than that of the snowpack, the result is a net gain of heat energy by the snowpack (U. S. Army, 1956, p. 160).

In most cases, the radiation from a forest canopy is comparable to that from clouds since a forest canopy, too, approximates a black body (U. S. Army, 1956).

Net radiation - The total of net solar radiation and net longwave radiation equals net radiation. This term is often used in energy budget calculations since it is more easily measured totally than any of the individual components. Net radiation values can vary greatly from season to season as well as from day to day. Seasonal differences are discussed quite thoroughly in _The Climate of Quebec - Energy Considerations_ by C. V. Wilson (1972). Daily differences are due mainly to cloud cover and temperatures.

When we look at the Edmonton area radiation data (Monthly Radiation Summary - AES), we may see a marked increase in daily and hourly values of net radiation converted to heat occurring near the middle of the snowmelt season (April 11, 1975 and March 17, 1976) (Figure 9). This is due to the depletion of snow cover and related albedo change. While received solar radiation values remain fairly constant (minor daily variations are due to cloud cover), net radiation increases greatly. This is due to the fact that with the removal of snow cover there is an increase in _net_ solar radiation because of the lower albedo of bare ground. Because no figures are available for _reflected_ solar radiation the increase is seen only in net radiation figures.

It should be pointed out that when discussing net radiation or longwave radiation received, what is actually meant is radiation absorption or conversion to heat.

5.2.3 _Convective Heat Transfer_

Convective heat transfer is the energy that is transmitted to the

FIGURE 9 - RADIATION PATTERNS

EDMONTON STONY PLAIN ALTA 53 33 N 114 06 W PYRANOMETER-KIPP CM6 APR 1975 AVR

TOTAL RADIATION FOR EACH HOUR ENDING AT (LOCAL APPARENT TIME) / RAYONNEMENT TOTAL DE CHAQUE HEURE SE TERMINANT À (TEMPS LOCAL APPARENT)

DAY QUANTIÈME	RF	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	DAILY TOTAL TOTAL QUOTIDIEN
01	1						1	11	26	40	51	61	65	65	61	52	40	26	11	1						510 E
02	1						1	11	25	38	51	57	66	64	59	50	41	25	11	1						499 E
03	1						1	5	9	23	51	56	50	45	37	39	26	14	7	1						363
04	1						2	9	17	34	42	39	47	60	47	43	24	13	5	1						383
05	1						1	9	22	42	51	56	55	64	62	54	43	22	12	2						494
06	1						2	10	24	35	44	54	55	57	47	36	27	19	8	2						420
07	1						2	13	19	40	48	63	64	66	62	52	42	32	12	2						517 E
08	1						1	3	8	17	31	27	28	34	28	21	19	11	6	1						234
09	1						1	4	5	18	32	46	46	38	34	26	19	12	5	1						285
10	1						2	13	25	43	55	63	67	67	63	55	44	30	14	3						543 E
11	1						3	15	30	44	55	64	67	67	63	56	43	29	12	3						550
12	1						3	15	28	44	55	60	62	66	62	53	44	29	14	2						535
13	1					+	3	13	28	31	37	34	43	38	39	36	25	17	7	2	+					353
14	1					+	1	3	7	7	11	14	15	14	13	11	9	6	3	1	+					114
15	1					+	1	2	6	14	M	M	M	M	29	19	16	11	5	1	+					M
16	1					+	3	12	30	39	41	55	59	60	46	27	34	24	8	3	0					440
17	1					+	2	8	17	32	50	56	66	68	59	55	43	30	15	3	+					502
18	1					+	3	10	21	39	44	59	61	53	60	43	29	14	7	3	+					445
19	1					0	3	13	21	24	31	25	29	27	10	7	7	5	2	1	+					206
20	1					+	4	19	35	48	59	65	70	20	16	47	44	24	8	2	+					460
21	1					+	6	16	20	38	50	65	61	76	64	49	46	32	16	6	+					544
22	1					0	5	18	32	45	55	62	M	M	M	M	M	M	M	M	M					M
23	1					M	M	M	M	M	M	M	M	M	M	M	M	25	11	3	+					M
24	1					+	6	21	35	47	57	63	61	67	61	57	36	20	9	5	+					544 E
25	1					+	4	14	18	27	39	38	59	55	40	35	42	34	10	4	+					418
26	1					1	7	19	33	46	56	63	67	67	63	57	47	34	20	7	1					588
27	1					+	1	1	3	4	6	9	13	18	18	15	9	8	7	2	+					115
28	1					+	3	10	29	49	60	67	67	70	60	56	40	33	23	7	1					575
29	1					1	5	13	37	43	50	61	46	35	40	32	27	14	15	7	1					425
30	1					+	3	5	18	30	42	69	71	70	63	54	33	18	7	2	+					485
MEAN MOYENNE						+	3	11	22	34	45	52	54	53	47	41	32	21	10	3	+					425

EDMONTON STONY PLAIN ALTA 53 33 N 114 06 W PYRRADIOMETER-CSIRO APR 1975 AVR

TOTAL RADIATION FOR EACH HOUR ENDING AT (LOCAL APPARENT TIME) / RAYONNEMENT TOTAL DE CHAQUE HEURE SE TERMINANT À (TEMPS LOCAL APPARENT)

DAY QUANTIÈME	RF	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	DAILY TOTAL TOTAL QUOTIDIEN
01	4	6-	5-	5-	5-	5-	5-	4-	3-	1-	0	1	2	2	2	2	1	2-	5-	6-	6-	6-	6-	5-	5-	71-
02	4	3-	3-	3-	3-	3-	3-	3-	5-	4-	0	3	4	3	3	3	2	1-	4-	6-	6-	5-	4-	1-	2-	41-
03	4	2-	2-	1-	2-	1-	1-	0	1	2	4	4	4	4	3	4	2	0	2-	2-	3-	3-	3-	3-	4-	0
04	4	5-	5-	3-	2-	1-	2-	0	1	2	2	2	4	6	4	5	2	0	0	2-	2-	2-	2-	2-	3-	0
05	4	2-	2-	1-	1-	1-	1-	1-	1-	1-	1	3	1	2	3	2	2	2-	4-	5-	4-	2-	2-	2-	1-	16-
06	4	1-	2-	3-	2-	2-	2-	1-	1-	2-	1	3	3	4	4	3	3	1	1-	4-	4-	1-	2-	3-	2-	9-
07	4	1-	1-	2-	2-	2-	2-	1-	1-	2-	1	3	3	4	4	3	2	1	3-	1-	1-	1-	1-	1-	1-	3-E
08	4	0	1-	1-	1-	1-	1-	0	0	1	1	1	1	1	1	1	1	0	1-	1-	1-	1-	1-	1-	1-	2-
09	4	1-	1-	1-	1-	0	0	0	0	1	M	M	M	M	2	2	1	1	0	1-	1-	2-	1-	3-	3-	M
10	4	2-	3-	4-	3-	1-	0	1-	1	1-	2	3	5	6	7	6	4	0	4-	6-	6-	6-	6-	6-	6-	21-
11	4	5-	5-	5-	5-	5-	5-	4-	1-	3	6	11	14	16	17	16	12	8	0	4-	5-	5-	5-	5-	5-	39
12	4	5-	5-	5-	5-	5-	4-	1-	5	13	20	26	30	36	35	30	24	14	3	5-	5-	5-	4-	4-	4-	178
13	4	4-	5-	5-	4-	5-	2-	4	15	20	28	24	30	27	27	24	17	11	3	2-	3-	3-	3-	2-	3-	186
14	4	4-	5-	4-	3-	1-	0	2	5	6	9	11	11	10	10	8	6	4	1	1-	1-	1-	1-	1-	1-	56
15	4	1-	1-	1-	1-	1-	1-	1	4	10	18	25	24	24	20	13	11	7	2	1-	1-	5-	6-	6-	6-	126
16	4	5-	5-	2-	1-	1-	0	6	17	25	26	35	38	37	29	18	21	12	3	1-	4-	4-	5-	3-	2-	234
17	4	2-	3-	3-	2-	2-	1-	4	10	19	30	33	40	40	33	30	21	12	2	5-	7-	7-	7-	7-	6-	223
18	4	6-	5-	4-	1-	2-	1-	4	12	24	28	37	39	34	37	25	15	6	1	2-	3-	3-	3-	2-	1-	231
19	4	1-	1-	1-	2-	2-	2-	4	11	15	20	17	20	19	7	5	5	3	1	0	0	0	1-	1-	2-	115
20	4	2-	2-	3-	3-	4-	3-	1-	5	14	28	41	46	12	10	29	25	11	0	3-	6-	6-	5-	5-	4-	176 E
21	4	5-	6-	6-	7-	7-	4-	5	10	23	30	39	37	49	39	28	25	15	5	3-	6-	6-	6-	7-	7-	236
22	4	7-	6-	6-	6-	6-	4-	4	14	23	31	37	38	33	35	28	18	10	2	2-	5-	5-	6-	5-	5-	211
23	4	4-	4-	5-	6-	6-	3-	5	13	22	29	33	32	32	30	28	23	10	2	2-	2-	1-	1-	4-	6-	217
24	4	5-	4-	4-	4-	3-	1-	5	15	25	31	36	35	40	35	32	18	8	1	2-	6-	6-	7-	6-	4-	229 E
25	4	4-	4-	5-	5-	5-	1	6	11	16	22	23	35	32	22	19	23	16	1	3-	6-	6-	5-	5-	5-	174
26	4	5-	5-	5-	5-	5-	2-	5	14	23	31	36	39	39	37	32	25	16	6	3-	7-	7-	7-	6-	6-	239
27	4	6-	5-	4-	2-	1-	0	1	2	3	4	7	9	13	13	10	6	5	4	1	1-	3-	1-	1-	1-	53
28	4	1-	1-	2-	2-	2-	1-	2	13	27	36	41	44	43	36	32	21	15	9	3-	7-	8-	7-	7-	7-	272 E
29	4	7-	7-	7-	7-	6-	3-	1	17	23	28	36	28	22	25	19	16	8	6	2-	6-	6-	6-	2-	1-	169 E
30	4	1-	1-	1-	1-	1-	1	3	11	18	25	45	42	41	37	31	17	9	2	1-	2-	1-	1-	0	0	269
MEAN MOYENNE		4-	3-	3-	3-	3-	2-	2	7	12	17	21	23	22	19	16	12	7	1	3-	4-	4-	4-	4-	3-	118

Source: Atmospheric Environment Service

FIGURE 9 - RADIATION PATTERNS

EDMONTON STONY PLAIN ALTA 53 33 N 114 06 W PYRANOMETER-KIPP CM6 MAR 1976 MAR

DAY QUANTIÈME	RP	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	DAILY TOTAL TOTAL QUOTIDIEN
		TOTAL RADIATION FOR EACH HOUR ENDING AT (LOCAL APPARENT TIME) RAYONNEMENT TOTAL DE CHAQUE HEURE SE TERMINANT À (TEMPS LOCAL APPARENT)																								
01	1							+	6	19	26	35	39	36	29	22	14	6	1							231
02	1							1	7	18	34	44	48	48	44	36	25	11	1							315
03	1							M	M	M	M	M	M	M	M	M	M	M	M							M
04	1							1	11	25	36	44	48	48	44	36	25	11	1							331
05	1							1	10	18	33	33	42	48	43	28	15	9	1							280
06	1							1	8	13	22	29	34	35	29	20	13	7	1							211
07	1							1	5	12	22	30	32	29	36	28	15	10	1							221
08	1							1	8	15	23	36	42	49	32	19	9	4	1							239
09	1							1	3	6	8	10	20	26	27	19	18	11	1							150
10	1							1	6	14	21	22	25	25	19	14	9	4	1							161
11	1							M	M	M	M	M	M	52	48	41	29	15	3							M
12	1							2	13	21	38	45	42	33	30	25	20	7	1							278
13	1							2	9	18	37	48	52	58	42	32	30	16	3							346 E
14	1							4	16	27	33	45	50	51	42	32	18	8	2							328 E
15	1							4	17	29	40	50	52	49	35	21	13	8	2							321 E
16	1							3	17	25	39	49	53	52	34	37	20	11	2							342
17	1						+	3	15	30	41	44	M	M	M	M	M	M	M	M						M
18	1						+	1	6	14	18	34	45	36	31	29	28	16	3	+						260
19	1						+	1	14	19	22	20	18	40	31	40	33	16	5	+						259
20	1						+	6	14	24	43	52	50	52	51	32	33	19	4	+						379
21	1						+	4	16	31	45	53	56	51	53	45	34	19	5	+						410
22	1						+	4	12	17	27	34	33	27	23	16	15	11	2	+						220
23	1						+	2	9	18	25	32	40	51	53	48	34	19	5	+						336
24	1						1	8	22	36	43	56	62	62	49	46	26	13	5	+						426 E
25	1						1	8	21	28	36	53	58	45	51	33	33	17	4	+						386
26	1						+	4	14	20	31	38	52	56	54	32	12	5	3	+						321 E
27	1						1	9	25	35	42	52	59	60	55	48	30	11	5	+						431
28	1						1	6	21	36	46	51	63	68	57	51	31	21	4	1						456 E
29	1						1	9	23	37	47	55	58	58	39	28	25	19	6	1						405
30	1						1	7	17	32	33	44	54	57	42	39	34	24	10	1						393
31	1						1	7	25	24	30	34	28	18	14	10	19	24	5	1						240
MEAN MOYENNE							+	4	13	23	32	40	45	46	39	31	23	13	3	+						312

EDMONTON STONY PLAIN ALTA 53 33 N 114 06 W PYRRADIOMETER-CSIRO MAR 1976 MAR

DAY QUANTIÈME	RP	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	DAILY TOTAL TOTAL QUOTIDIEN
		TOTAL RADIATION FOR EACH HOUR ENDING AT (LOCAL APPARENT TIME) RAYONNEMENT TOTAL DE CHAQUE HEURE SE TERMINANT À (TEMPS LOCAL APPARENT)																								
01	4	4-	3-	4-	2-	2-	2-	3-	2-	1	1	1	1	1	1	0	0	1-	1-	2-	2-	2-	2-	2-	2-	28-
02	4	2-	3-	3-	2-	2-	2-	2-	2-	3-	1-	0	0	0	0	1-	2-	4-	4-	5-	5-	5-	5-	3-	4-	60-
03	4	5-	5-	5-	4-	4-	4-	3-	M	M	M	M	M	1-	1-	1-	3-	5-	6-	5-	5-	4-	1-	3-	3-	M
04	4	2-	3-	6-	6-	6-	5-	4-	4-	2-	1-	0	1	0	1-	2-	3-	5-	6-	5-	5-	5-	5-	5-	3-	81-
05	4	2-	3-	4-	0	0	2-	4-	2-	0	3	3	4	3	3	1	3-	5-	6-	5-	3-	2-	1-	1-	2-	26-
06	4	3-	2-	2-	6-	6-	3-	1-	2-	1	3	4	5	4	3	2	1	0	1-	1-	1-	0	0	0	0	6-
07	4	0	0	1-	1-	0	0	1-	0	1	1	2	2	3	5	1	0	3-	4-	2-	1-	1-	1-	1-	2-	3-
08	4	6-	3-	3-	2-	2-	3-	2-	1-	1	3	5	6	9	7	4	2	0	1-	1-	1-	1-	1-	0	0	10
09	4	0	0	0	0	0	0	M	M	M	M	M	2	1	1	1	1-	3-	4-	3-	3-	2-	1-	0	1-	M
10	4	0	1-	0	1-	1-	1-	1-	0	1	2	2	2	2	2	1	0	0	1-	1-	1-	2-	2-	2-	2-	5-
11	4	4-	5-	4-	4-	4-	3-	4-	3-	2-	0	1	1	1	2	2	0	4-	6-	6-	7-	6-	5-	5-	4-	69-
12	4	3-	2-	1-	2-	2-	3-	2-	1-	2	1	4	4	3	3	3	1	1-	1-	3-	4-	5-	6-	7-	6-	28-
13	4	4-	3-	3-	4-	2-	1-	0	0	1-	0	2	3	6	4	2	1-	4-	6-	7-	6-	6-	5-	4-	4-	45-
14	4	2-	5-	5-	4-	5-	5-	4-	3-	0	2	3	3	3	3	3	2	0	1-	3-	4-	5-	5-	6-	6-	43-
15	4	6-	6-	6-	5-	5-	5-	5-	3-	1-	2	4	4	5	4	2	1	0	1-	1-	0	1-	1-	2-	2-	27-
16	4	2-	1-	3-	1-	1-	3-	5-	3-	0	3	4	5	6	5	6	5	2	1	3-	2-	0	3-	4-	5-	2
17	4	6-	5-	4-	4-	3-	3-	3-	0	5	10	11	14	16	14	9	4	2	0	3-	3-	3-	4-	4-	4-	36
18	4	4-	4-	4-	2-	1-	1-	0	3	8	11	19	25	22	19	17	14	4	4-	4-	2-	3-	1-	1-	2-	108 E
19	4	3-	2-	1-	1-	1-	1-	0	6	12	15	14	13	26	20	24	15	3	5-	7-	6-	5-	7-	3-	3-	100
20	4	2-	5-	6-	6-	5-	5-	4-	3	10	19	26	27	31	29	16	16	5	3-	4-	2-	2-	3-	4-	6-	125
21	4	4-	2-	2-	4-	4-	4-	0	6	14	26	33	36	33	33	26	17	5	4-	7-	7-	7-	6-	6-	6-	167
22	4	3-	4-	4-	6-	3-	2-	1-	5	M	M	M	M	M	M	M	9	5	0	2-	4-	4-	6-	5-	5-	M
23	4	3-	1-	1-	1-	1-	2-	1-	2	6	12	17	25	33	34	29	17	7	4-	8-	7-	8-	8-	8-	7-	123
24	4	7-	8-	7-	7-	6-	7-	4-	6	18	26	38	45	43	31	28	14	4	3-	6-	7-	7-	7-	7-	7-	162
25	4	7-	7-	7-	7-	7-	6-	2-	8	18	24	36	40	31	33	20	19	4	2-	4-	4-	5-	7-	8-	8-	154
26	4	8-	8-	7-	6-	5-	4-	1-	6	12	20	26	35	37	32	16	8	2	1-	4-	3-	5-	7-	8-	8-	118
27	4	8-	8-	8-	8-	8-	7-	1-	12	21	27	35	40	39	34	27	15	4	3-	7-	5-	6-	7-	7-	7-	166
28	4	7-	7-	7-	7-	7-	5-	3-	10	22	30	37	40	46	35	29	18	5	4-	4-	6-	5-	5-	5-	6-	196
29	4	7-	5-	7-	7-	5-	6-	1-	10	22	30	36	38	36	24	17	13	9	2-	6-	5-	5-	4-	3-	5-	167
30	4	5-	5-	5-	4-	4-	4-	1	9	20	21	29	35	36	25	22	17	9	2-	6-	6-	6-	6-	6-	6-	160
31	4	6-	5-	6-	7-	6-	5-	1-	13	17	21	24	20	12	9	6	12	11	0	3-	3-	3-	4-	4-	7-	84
MEAN MOYENNE		4-	4-	4-	4-	4-	3-	2-	3	7	11	15	16	16	14	10	7	2	3-	4-	4-	4-	4-	4-	4-	49

Source: Atmospheric Environment Service

snowpack from the air by convection. Through turbulent transfer both heat and water may be transferred toward or away from the snowpack. When the ground is completely snow covered, the amount of heat added to the snow surface can be calculated using equations for turbulent exchange (Gray and O'Neill, 1973, U. S. Army, 1956). A downward temperature or vapor pressure gradient directs energy toward the snow while an upward gradient reduces the amount of energy available for melting.

Convective heat transfer is a difficult parameter of the energy balance to evaluate because it is not easily measured. Air temperature and vapor pressure immediately above the snowpack as well as wind speed and temperature may all vary greatly locally due to such factors as forest cover and topography.

Next to radiation, convective heat transfer is the major factor affecting the rate of snow melt. In the Canadian Prairies it has been determined that during the initial stages of snowmelt when the ground was still fully covered, the most important source of heat energy to the snowpack was net radiation (Gray and O'Neill, 1973). As the melt progressed and bare ground appeared, the transfer of sensible heat became the dominant snowmelt factor. As bare ground became apparent, the heat available from the bare areas had a greater effect on melting. Although this study holds true in the more central areas of the Prairies, it does not hold as rigidly for the Edmonton area. In this area the effect of Pacific air masses and associated chinooks play a major role.

During the snowmelt season in the Edmonton area two types of air mass are usually dominant; cold arctic air masses and milder Pacific

maritime air. The greatest melting is brought about by these milder Pacific air masses due to the warmer temperatures, higher wind speeds and greater humidities which are associated with them. The earlier melting of the snowpack was due in part to the earlier dominance of Pacific air masses.

5.2.4 Latent Heat of Vaporization

Latent heat of vaporization refers to the amount of heat available to the snowpack from the change of state of water. The amount of heat necessary to evaporate 1 gram of water varies from 540 calories at 100°C to approximately 600 calories at 0°C (Zumberge and Ayers, 1964; Critchfield, 1966). The term latent heat is used because when water vapor condenses to form one gram of water the same amount of heat is released. The heat involved in change of state from water to ice is known as latent heat of fusion. The amount of heat required to change one gram of ice to water is 80 calories.

As warm air near the surface of the snowpack is cooled by the snowpack, water vapor begins to condense. Due to the difference between the heat of vaporization and the heat of fusion, for every gram of water that condenses, enough heat is released to melt about 7 grams of snow.

As mentioned earlier, the air masses responsible for the most snowmelt in the Edmonton area are maritime Pacific air masses. These air masses are much warmer than the dominant arctic air masses. Because of their higher temperature and maritime origin they are able to hold much more moisture than arctic air masses. Foster (1949) states that maritime Pacific air masses are able to hold 6 to 10 times the moisture of arctic air masses (3 to 5 grams per kilogram of air for

Pacific compared to 0.5 grams per kilogram for arctic). Some of this moisture is lost in movement over the mountains; however, maritime Pacific air masses that do arrive in the Edmonton area hold sufficient water vapor to cause great amounts of snow melting.

5.2.5 Conduction of Heat from the Ground

This is the amount of heat directed toward the snowpack from the underlying ground. In the Edmonton area, this term is of some importance to snowmelting in the early fall and in the late stages of snowmelt; however, for the greatest part of the snowmelt season the ground remains frozen, so this source of heat is virtually negligible. Also, in some places the snow cover is shallow enough to be translucent which allows some penetration of light and thus conversion to heat at the ground surface, but this effect is minor.

5.2.6 Heat Content of Rainwater

When rain falls on a snow surface it is cooled to freezing by the snowpack. As it is cooled this heat and the heat of fusion are added to the snowpack. The amount of heat available is directly proportional to the amount of rain falling and the temperature of the rain. On snowpacks with subfreezing temperatures, rain tends to bring the temperature of the pack to freezing, while if a snowpack is already isothermal at 0°C, rain causes melting. The actual amount of melting caused by rain is small. It would take 1 inch (25.4 mm) of rainfall at 46°F (7.8°C) to produce .1" (2.54mm) of melt water (U. S. Army, 1956, p. 180).

During the 1975 field season there were two rainfalls of significant amounts. On April 19, 3.6 mm of rain at a temperature of approximately 5°C fell. At the time the temperature of the snowpack

was still below freezing. This rain had the effect of raising the temperature of the snowpack to near freezing. Another rain of 5.8 mm at approximately 4.5°C fell on April 27. Since much of the snow was gone by this time, this rain probably had little effect on increasing snow melting rates.

In conjunction with the effect of rainfall on snowmelt, it should also be noted that the air masses associated with rainstorms are high in humidity, causing increased condensation on the snowpack. These factors combined can have a significant effect on the rate of snow melting.

5.3 Ripening of the Snowpack

The thermal quality of the snowpack determines the amount of snowmelt that results when heat energy is added to the snowpack. During the snowmelt period the temperature of the snowpack has been raised to an isothermal 0°C. In addition, a certain amount of free water may be present. The process of a snowpack changing from small loose snow crystals to large grains with water present is called ripening (U. S. Army, 1956, p. 286). When a snowpack is completely ripe, any amount of energy added to the snowpack produces runoff.

The density of the snowpack refers to the relationship between water equivalent of the snowpack. It can be obtained by dividing the water equivalent of the snowpack by the depth of snow (Foster, 1948). A chart of snow densities according to type of snow is presented by Gray (1970, p. 225). Ripe snow generally varies between .40 and .50 (Gray, 1970, Garstka, 1970).

5.4 Conditions Leading to 1975 Melt

In the spring of 1974, snowmelt runoff was much greater than

normal and it caused flooding in many areas. Using soil moisture indices this flooding was predictable (Laycock, 1974), however, it was not totally a result of above average precipitation in one year alone.

With respect to long term Edmonton area climatic patterns (1880 to the present), since 1961 when climatic records were first taken at the Edmonton International Airport the climatic trend has been relatively dry. Yearly precipitation has been less in many years than the yearly averages for the first part of the century. Deficits have been high and there have been surpluses in relatively few years. With the exception of 1965, in all years up to 1972, yearly deficits exceeded surpluses at the 10 centimeter storage level (Appendix I). In 1972 surpluses exceeded deficits at all storage levels. The same was true for 1973. Above average amounts of snowfall during the winter of 1972-1973 recharged soil moisture in most storage categories (an exception was the 25 centimeter level). The summer of 1973 showed above average precipitation and none of the recorded soil moisture storage levels experienced a deficit. The snow fall for the winter of 1973-74 was well above normal and by spring snowmelt all storage categories showed surpluses. In the years since 1961 when soil moisture tables were first kept using Edmonton International Airport data, 1974 was the first year to show a surplus at the 25 centimeter storage level. The prospect of surpluses for even the 25 centimeter storage category led to the prediction of flooding for many areas of Alberta in the spring of 1974 (Laycock, 1974).

The last half of 1974 was the opposite (Figure 5). All months experienced below normal precipitation and high amounts of potential evapotranspiration. By October all but the 25 centimeter storage

capacity had experienced deficits. Snowfall for the winter of 1974-75 was well below normal. By the spring snowmelt the total amount of winter precipitation was sufficient to completely recharge only the 1.25 and 5 centimeter storage levels.

Using strictly soil moisture storage indices to predict runoff (Chapter IV), it would be expected that the only runoff would occur from roadways, railroad tracks, residences and fallow fields. There was measurable runoff at several sites and a discussion of the patterns and sources of the runoff follows.

5.5 1975 Snowmelt - Meteorological Factors

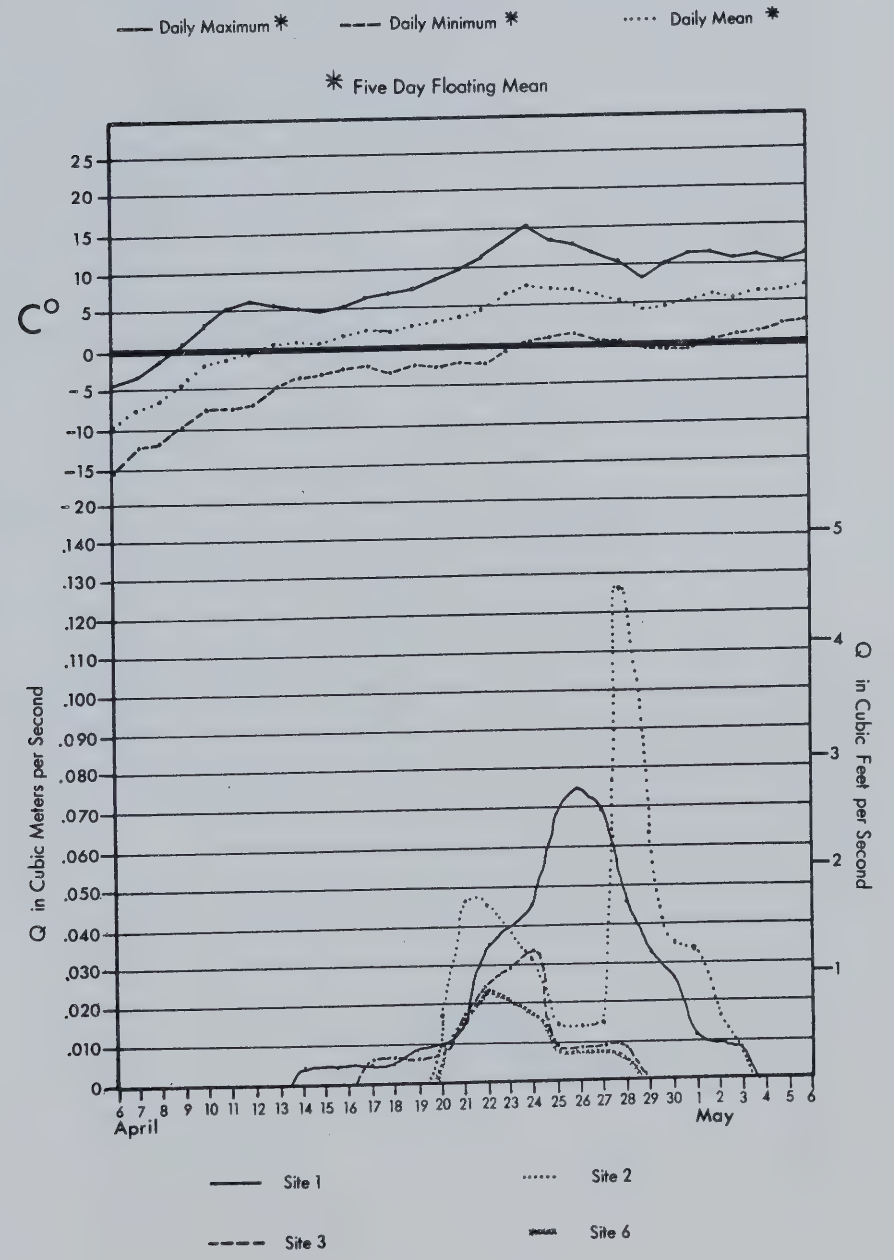
As mentioned previously, the last half of 1974 was extremely dry and caused soil moisture deficits at all but the 25 centimeter storage capacity and there was major storage depletion at that level. The total snowfall amount for the winter of 1974-75 was 92.26 centimeters. Using a 5 day moving mean, maximum daily temperatures rose above freezing on April 9 (Figure 10). The first actual day with a maximum above $0^{\circ}C$ was April 10. This was somewhat later than usual and mean daily temperatures rose to $5^{\circ}C$ by April 11. Average daily mean temperatures rose above $0^{\circ}C$ by April 13 and average daily minimum temperatures rose above freezing on April 24.

This rapid late season warming led to a quicker runoff than usual. The average temperatures rose so quickly that the snow ripened and ran off quickly as well. In most places, some of the runoff occurred before the ground had thawed leading to higher than expected runoff figures.

The first noticeable runoff was detected on April 14 at Site 1. Measurable flow (approximately .028 cubic meters per second - 1 cubic

FIGURE 10

SNOW MELT SEASON
TEMPERATURES AND HYDROGRAPHS
1975

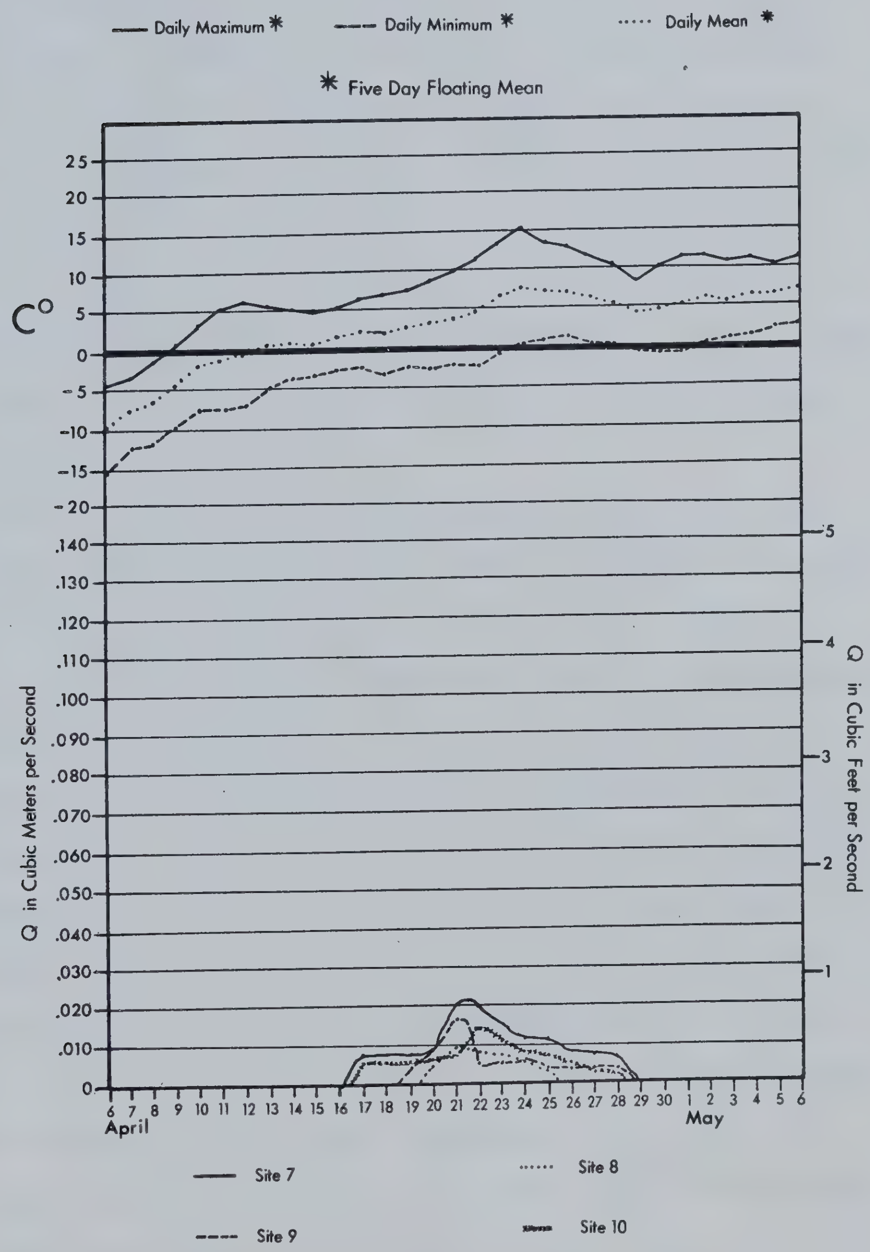


Source: Edmonton International Airport Met. Data

N.B. - Hydrograph data source - Field observations by author

FIGURE 10

SNOW MELT SEASON TEMPERATURES AND HYDROGRAPHS 1975



Source: Edmonton International Airport Met. Data

N. B. - Hydrograph data source - Field observations by author

foot per second) did not begin at any site until April 20 and ended approximately on May 1. The beginning of significant runoff on all sites was related to the precipitation of April 19. On that date the maximum temperature was 8.9^{o}C and minimum temperature was -0.6^{o}C. During the day 3.6 millimeters of rain and 6.9 centimeters of snow fell for a total of 5.8 millimeters of precipitation. The heat provided by this rain and wet snow to the already ripened snowpack triggered the rapid melting that was observed as runoff beginning on April 20. In addition, 1.0 millimeters of rain fell on April 23 and an additional 5.8 millimeters of rain fell on April 27. For the most part these rains had little effect on inducing greater melting from the test basins.

The flows depicted on the hydrographs are daily average flows (Figure 10). During the field season, most of the daily flow measurements were taken during the afternoon near the time of peak flow. Ideally, measurements should have been taken three to four times daily at the same time at each site to establish the effects on the flow of the diurnal patterns of temperature and solar insolation as well as the effects of cloud cover and winds. This was impossible due to the time involved in driving from site to site as well as time constraints on the author. To make up for this, corrections were used to account for variations in flow due to variable meteorological as well as basin storage factors. In sub-basins with a great deal of surface detention storage (Plots 1, 2 and 3), daily average flow would be quite low (less than one-half the maximum) in the initial stages and over one-half maximum daily flow recorded during the later stages. Basins with little surface detention storage would show a much greater response to

changing patterns, especially solar insolation and temperature changes and in most cases daily average flow would be much less than daily maximum flow. Only some of these patterns are based on direct observation. Others are based upon observations made by Erxleben (1972) in this area and others such as Kakela (1969) and Landals (1970) in other areas.

5.6.1 Individual Site Runoff - Site 1 - 107.3 Hectares

Site one is a culvert under a section road located approximately 2 kilometers northwest of North Cooking Lake. It is in the Cooking Lake drainage basin. The 107.3 hectare drainage area above the culvert is centered around a large slough. Shoreline and forest cover make up most of the rest of the sub-basin.

Runoff began earliest at Site 1, April 14 (Figure 10). It was so small as to be unmeasurable until a week later, April 21. The maximum daily average flow was .13 cubic meters per second (4.7 cfs) on April 25. This tapered to less than .014 cubic meters per second on May 3. The total volume of flow was 4.4 hectare meters (35.6 acre feet) or 4.1 centimeters per unit area. This volume of runoff was extremely high compared to expected runoff (Chapter IV, Section 4.4.1) but can be explained at least partially in terms of local factors.

Initial runoff came largely from the south facing slopes along the railroad tracks and on the north edge of the slough. Although they rarely have 40^{o} slopes, they would have received more insolation due to their south facing nature. The hydrograph for Site 1 is relatively smooth due to the high amount of detention storage provided by the slough. An example of the detention storage is the delayed response to the rain and snow of April 19. Nearly all of the other

sites showed a rapid increase on April 20 or 21 while Site 1 shows no significant change until one day later, April 22.

The high volume of flow recorded may be due to two factors. There was significant drifting along the railroad tracks and the edges of the slough where soil moisture storage values are low. The melt from these drifts would go mainly to runoff. Also, much of the measured flow could be groundwater flow. After a series of wet years, such as 1972 to 1974, there can be a significant amount of groundwater discharge as much as a year later. This could also account for the lengthened hydrograph. There was no evidence of surface outflow from Antler Lake through this sub-basin. If the area above the sub-basin is included the average yield would decrease from 4.1 centimeters to approximately one-tenth that amount.

5.6.2 Site 2 - 280.1 Hectares

Site 2 is a culvert on a ditch draining an area of varied land use in the Hastings Lake Basin. The culvert is located under a road approximately 1.5 kilometers southeast of Deville. The most notable feature of this test plot is a large drained slough just north of the plot which now serves as a hay meadow (Plate 2).

The runoff measured at Site 2 had the most irregular discharge of all the sites gauged. Runoff was first noticed on April 20. It peaked at .045 cubic meters per second (1.6 cfs) on April 22 and began to taper off until a second, higher peak of .14 cubic meters per second (5.1 cfs) was measured on April 28. The total volume of flow measured was 4.4 hectare meters which amounted to 1.6 centimeters average yield.

The double peaked hydrograph is easily explained by the physical

appearance of the basin. The ditch which drains the slough is approximately 1.5 to 2 meters deep along the east bank. Because of this, the ditch was subject to deep drifting. The first minor peak in the hydrograph came from meltwater in two small channels which drained wooded areas on either side of the old slough. These channels joined the main drainage channel near the upper end of the culvert. Later in the melt period, as the drift in the main channel melted completely (due partially to the rain of April 27), the water which had ponded on the floor of the old slough was released, causing the second major peak on the hydrograph.

The volume of runoff (1.5 centimeters) was higher than expected (Chapter IV, Section 4.4.2). The source of this runoff was mainly due to drifting, especially around the shore of the old slough and in the drainage channel. Groundwater was also probably a part the total runoff. This can be seen in the long taper of the hydrograph, with flow detected as late as May 3.

In years of above average precipitation there is outflow from Wanisan Lake through test plot no. 2 and on into Hastings Lake. In 1975, however, there was no evidence of outflow from Wanisan Lake. If the area above sub-basin two is included in total yield calculations, the average yield would be approximately 0.5 centimeters.

5.6.3 Site 3 - 54.6 Hectares

Site 3 is a culvert under a road 3.5 kilometers southeast of Deville. Test basin number 3 had mainly a forest cover surrounding a small slough. Approximately 40% of the plot was in agricultural use.

Runoff from Site 3 began on April 17 and peaked at .03 cubic meters per second on April 24. The total volume of runoff was 1.4

hectare meters. This amounted to an average yield of 2.6 centimeters.

As with Sites 1 and 2, much of the flow measured at Site 3 came from drifts and possibly partially from groundwater flow. The volume of flow per unit area was high due to the amount of runoff which came from drifts between the roadside and the railroad tracks which had low storage capacities. Much of the area near the culvert of Site three was low storage area. Since there was little overland flow and therefore little chance for infiltration, much of the meltwater from the drifts went as runoff.

The effects of the slough in regard to detention storage are evident at Site 3 just as at Site 1. The hydrograph is much smoother with flow beginning earlier and continuing,even at a low flow rate, longer. The effects of the precipitation on April 19 are not evident until 2 to 3 days later.

5.6.4 Site 4 - 107.5 Hectares

Site 4 is a culvert on the channel of what was once Cooking Lake Creek between Cooking and Hastings Lakes. The culvert drains an area of 107.5 hectares which is mainly pasture land (rough and improved). Much of the area is low lying and marshy.

It was expected that this site might yield at least some runoff (Chapter IV, Section 4.4.4); however, no flow was recorded. Evidence of melting was first noticed on April 20 with a significant amount of ponding behind the culvert which was still clogged with ice and snow. Even after hand clearing around the mouth of the culvert the body of the culvert remained fairly iced up and no flow was recorded. By May 8, most of the water which had ponded behind the culvert had either percolated into the ground or evaporated.

5.6.5 Site 5 - 148.9 Hectares

Site 5 is a culvert on a ditch draining a plot of varied land use centered around a large slough known as Sisib Lake. In times of outflow it drains toward Hastings Lake.

No outflow was recorded at Site 5. Any runoff went toward Sisib Lake with most of the melt going to recharge soil moisture storage. There was no evidence of drifting and while there had been significant outflow in 1974, there was no evidence of outflow in this year.

5.6.6 Site 6 - 57.0 Hectares

Site 6 is a culvert under the road which runs along the west end of Hastings Lake. It drains a plot of agricultural use, mainly crops and improved pasture. The plot has a slightly northward slope. Runoff was first noticed on April 20, and peaked at .02 cubic meters per second on April 22. Flow tapered off to less than .01 cubic meters per second on April 25. The total volume measured was 1 hectare meter and average yield was 1.8 centimeters.

Most of the runoff from Site 6 came from a deep roadside drift. This drift had been added to by snow which had been removed from the road. There was little or no contribution from groundwater.

Due to the slight north facing slope of most of the plot, snowmelt started later than at most other sites. The beginning of the runoff was related to the precipitation of April 19. Flow peaked and tapered off rapidly due to a lack of surface detention storage.

5.6.7 Site 7 - 55.6 Hectares

Site 7 is a culvert running under Highway 14 south of Hastings Lake. The test plot it drains is of varying land use, approximately 50 per cent rough and improved pasture and 50 per cent forested.

Runoff began on April 17 and peak flow of .02 cubic meters per second was measured on April 21. Flow fell to approximately .01 cubic meters per second on April 24. Flow ceased on approximately April 29. The total volume of flow was 1.1 hectare meters for an average yield of 2.1 centimeters.

Runoff at Site 7 was nearly the same as that for Site 6 in terms of average yield. There were differences in the regime of flow, however. Runoff at Site 6, with more open area and agricultural land, came over a shorter period of time than Site 7. The hydrograph of Site 7 was less peaked due to the influence of the forest, delaying and prolonging the melt period. Runoff came mainly from drifting around the edges of the forested area.

5.6.8 Site 8 - 29.6 Hectares

The culvert of Site 8 was located under a section road along the north side of Joseph Lake. The site was a small, relatively flat agricultural site. Runoff began on April 20 and had ended by April 27. The maximum daily average flow was only .008 cubic meters per second and the total volume was .3 hectare meters. The average yield amounted to 1.1 centimeters. There was virtually no drifting on test plot number 8. The measured runoff came from snow very near the culvert where flow was gauged. A small farm house and the associated buildings were immediately next to the main drainage channel of the plot. It was predicted (Chapter IV, Section 4.4.8) that runoff would be somewhat less, but because of the quick melting of the snowpack combined with the fact that the plot was small and very little was lost to overland flow, more runoff than expected was measured.

5.6.9 Site 9 - 284.3 Hectares

The culvert at Site 9 drained the largest (284.3 hectares) plot of the study. The sub-basin was mainly agricultural land, situated along the western edge of Joseph Lake. The culvert was located approximately in the middle of the test plot. South of the culvert, the plot has a slightly northward face while north of the culvert the plot is forested and rather flat.

Although Site 9 was the largest in terms of area, the total runoff was smallest in terms of average yield. Total volume was .6 hectare meters for an average yield of .2 centimeters. Runoff began following the rain and snow of April 19 on April 20. The maximum daily average flow was recorded on April 21 and had tapered to less than .005 cubic meters per second by April 25.

As expected, melting began earliest from the fallow field in the southwest corner of this test plot. There was very little runoff from this field however, since most of the meltwaters went to soil moisture recharge. There was very little drifting on test plot number 9. The runoff from areas of slight drifting (forest edges) had to reach the culvert by mainly overland flow and consequently most was lost to infiltration, the same as the runoff from the fallow field.

5.6.10 Site 10 - 59.9 Hectares

Site 10 is a culvert running under the entrance road to Joseph Lake Park. The sub-basin it drains is all in agricultural use, mainly arable land and improved pasture. The plot has a slightly north-facing aspect, sloping toward Joseph Lake. The total snowmelt yield was .7 hectare meters and average yield was 1.2 centimeters.

Runoff began on April 17 and the maximum daily flow was measured

on April 23 at .014 cubic meters per second. Analysis of the hydrograph of Site 10 shows the effect of drifting on detention storage. Virtually all of the runoff measured at Site 10 came from a large roadside drift. The drift was approximately 1 kilometer long and 1.5 meters deep (Witter, 1976, p. 27, plate 3). Very little runoff was detected from the adjoining field.

The effect of detention storage is shown by the smooth curve of the hydrograph, beginning earlier and lasting longer than similar sites without a great deal of detention storage (Site 6). The hydrograph did not show a response to the rain and snow of April 19 until 3 days later on the 22nd.

5.7 Discussion of Melt Patterns

As mentioned earlier (Chapter IV), using soil moisture indices as a method for approximating runoff, it was predicted that very little runoff could be expected. In most cases, though, the measured runoff patterns were greatly different than expected patterns and there were great variations from site to site as well as between basins. Measured runoff amounts were greater than expected in all but one of the test basins which showed measurable runoff and in most cases were greater than area averages.

From the test basins in the Cooking and Hastings Lake Basins, runoff amounts varied from 4.1 centimeters at Site 1 to 1.5 centimeters at Site 2. It should be noted that two of the sub-basins chosen contributed no runoff.

Table 3 illustrates the lake level rises recorded from the fall of 1974 to the spring of 1975. In all cases, the rises shown by the lakes and the average basin yield necessary for such rises are much

TABLE 2

DRAINAGE BASIN CHARACTERISTICS

in Hectares

Lake	Total Drainage Basin	Water Area (June, 1975)	Drainage: Lake Ratio	Forest Area	Cleared Area
Cooking	18,662	3685	5:1	7351	7026
Hastings	10,627	1000	11:1	5046	4415
Ministik	9,056	1130	8:1	5682	2244
Oliver	3,888	423	9:1	3276	189
Joseph	3,402	697	5:1	608	2097
Miquelon #1	5,913	737	8:1	3086	2090

Sources: EPEC, 1976, Crawford, 1976

TABLE 3

LAKE LEVEL RISES

Lake	Cooking (1119 H)	Hastings (295)	Ministik (335)	Miquelon (224)
1975 - 1976				
Rise in cm	4.9	4.3	7.6	5.8
Yield (HM)	177	43	43	84
D:L Ratio	2:1	5:1		
Average Basin Yield (cm)	1.0	.4	.8	1.0
1974 - 1975				
Rise in cm	15.2	11.2	11.4	11.2
Yield (HM)	560	111	84	123
D:L Ratio	2 or 3:1	5:1	4:1	4:1
Average Basin Yield (cm)	3.0	1.0	1.3	1.5
1973 - 1974				
Rise in cm	53.3	57.9	36.6	38.1
Yield (HM)	1959	577	280	401
D:L Ratio	5:1	6:1	3:1	4:1
Average Basin Yield (cm)	10.4	5.3	4.6	4.8
1972 - 1973				
Rise in cm	20.1	19.8	16.3	
Yield (HM)	737	197	178	
D:L Ratio	5:1	9:1		
Average Basin Yield (cm)	4.1	2.3	2.0	

Source: Water Survey of Canada

higher than the predicted yields. For all of the basins except the Cooking Lake basin, however, they closely approximate the average yield from the Whitemud basin for the same year (Table 4). The average yields for all the basins which contributed runoff in the Hastings Lake basin were all near 2 centimeters. If the figures are close to correct, the drainage area to lake area ratio for Hastings Lake in 1974-75 must have been approximately 5:1 (Table 3).

There are several possible reasons for the far above predicted amounts of runoff that were recorded. Perhaps the major reason is the meteorological conditions during the melt season. Daily temperatures remained quite low until early April (Figure 10), much later than in a normal year. When temperatures (daily maximum, minimum and mean) did rise above freezing, they continued to rise rapidly. Daily maximums rose above freezing on April 9 and by April 15 had risen above $5^{o}C$ to stay. On April 13, daily mean temperatures rose above freezing and by April 24, daily minimum temperatures rose above $0^{o}C$. This rapid rise in temperature allowed the snowpack to ripen and run off quickly. Although the fall of 1974 was dry, some precipitation, both rain and snow did fall in November before the ground had completely frozen. Little of this moisture would have been lost to transpiration and evaporation. Thus when warming took place so rapidly in the spring, the ground did not have time to thaw before meltwater was produced. In most places this caused the amount of snowmelt water available to exceed infiltration rates and go as runoff rather than to soil moisture recharge.

Another factor which greatly influenced the amount of runoff is drifting. Drifting is quite common in the Cooking Lake moraine due

TABLE 4

APPROXIMATE SPRING SURPLUSES

	Whitemud Basin (368 sq. km.)		Vermilion Basin (896 sq. km.)	
	Total Volume (HM)	Average Yield (cm)	Total Volume (HM)	Average Yield (cm)
1976	238	.6	295	.3
1975	456	1.4	884	.6
1974	4663	13.8	11393	7.5
1973	910	2.5	1181	1.2
1972	1493	4.1	2054	2.1

Source: Water Survey of Canada

to the knob and kettle topography and the amount of forest cover. At many sample sites the runoff from drifts showed up directly as runoff. This was due to their location along roadside drifts (Sites 1, 3 and 6), or along drainage ditches (Site 2). In these areas, soil moisture storage capacities are low and the meltwater runs off rapidly in well established drainage channels. The drifting patterns and estimates of surpluses from drifts in the Cooking Lake moraine are referred to by Witter (1976). Kakela (1969) discusses the effects on water balance of areas which experience drifting. This effect will be discussed in relation to the Cooking Lake moraine, in Chapter V, Section 5.15.1.

Also, a factor which affects the amount of runoff measured is groundwater flow. Meyboom (1963) states that in the Prairies, groundwater flow is often directed toward minor depressions. These depressions then serve as evaporation basins for the water that reaches them. During the summer, much of this water is used and transpired by phreatic vegetation, but when there is no vegetation growth taking place (melt season), much of this groundwater goes as runoff if the body of water is at peak storage. This was the case for some of the test sites in 1975. In most cases, the amount of groundwater flow cannot be determined accurately since it is impossible to differentiate groundwater flow from snowmelt runoff in a study of this sort. In the lower part of larger sub-basins (Sites 1 and 2), groundwater flow may be even more important than in separate basins.

Other factors which could affect the amount of surplus include differences in temperature and precipitation between the International Airport and the moraine (Chapter VII, Section 7.3.1). The difference could mean lower evapotranspiration and higher precipitation values

for the moraine area. Also, storage capacity estimates could be off. Much of the basin could be in a lower storage capacity than originally estimated.

Table 4 shows the approximate spring surpluses in the Whitemud and Vermilion basins. The Whitemud basin is a basin of 368 square kilometers located to the west of the moraine. The Vermilion River is gauged at Vegreville, east of the study area, and covers 896 square kilometers. In the Vermilion River basin especially a large amount of drainage is into local depressions, some of which have been drained. These undrained sites may have no outflow in drier years and the basin area varies from year to year. Data from the spring of 1975 show average yield amounts of 1.4 centimeters for the Whitemud basin and 0.6 centimeters for the Vermilion basin.

Comparing this with Table 4, we can see that the average yield for Cooking Lake is much higher than the area averages while the yields for Hastings Lake are very near the area averages. Measured runoff for both basins, however, shows yields approximately twice the basin average. Because of this, the drainage to lake area ratios listed on Table 3 are only half the regular ratios listed on Table 2.

In most cases the sub-basins chosen for study are near the lakes and contribute directly to the lakes. Usually, though, the sub-basins chosen were only the lower end in a chain of drainage toward the lakes. The best examples are Site 1 which receives drainage from north of Cooking Lake, specifically Antler Lake and Site 2 which, in wet years, receives overflow from Wanisan Lake. These areas contribute only in wet years and so in those years the drainage areas of the main lakes are enlarged, showing the patterns described by Stichling and Blackwell

(1967). Since there was no surface outflow from the areas above the test basins, the actual drainage to lake area ratios must be considered to be only approximately one-half the normal ratios. Runoff is approximately twice the basin average, though, due to the factors previously discussed.

5.8 Conditions Leading to the 1976 Melt

Conditions leading to the spring of 1976 were much the same as those in 1975. After the snowmelt of 1975, although all soil moisture levels had not been completely recharged, most had been nearly recharged. May and June were moderately wet months and after the first half of the year, no storage level showed a deficit. July and September both experienced deficits of precipitation of over 5 centimeters. By the end of September the 5 and 10 centimeter storage levels were experiencing deficits and the 15 and 25 centimeter storage levels were severely depleted.

The winter of 1975-76 experienced below average precipitation, just as in the winter of 1974-75. The total of winter snowfall amounted to 102.3 centimeters compared to 131.2 which is normal. Of the soil moisture storage categories used in this study, only the 1.25 and 5 centimeter storage level could have been fully recharged from snowmelt available by the end of March.

The 1976 melt season was a direct contrast to that of the previous year. In 1975, temperatures remained quite cold through March and the first week of April. When temperatures did climb above freezing they rose rapidly which caused the snowpack to ripen and run off quickly.

In 1976, after a cold spell in the first few days of March,

average daily maximum temperatures rose above freezing on March 14 (Figure 11). Average daily minimum temperatures did not rise above freezing until April 8. During this period the daytime thawing and nightly freeze-up allowed a slow ripening of the snowpack. At the same time, it allowed a gradual thawing of the ground. This combination of factors led to a maximum infiltration of snowmelt waters. In addition, there were no rains during the 1976 snowmelt season, so no heat was added to the snowpack by this means.

The first trip into the field was made on April 3 at which time there was flow only at Site 1. Trips were made at least every other day until April 12 when measurable flow had ceased at all sites except Site 1.

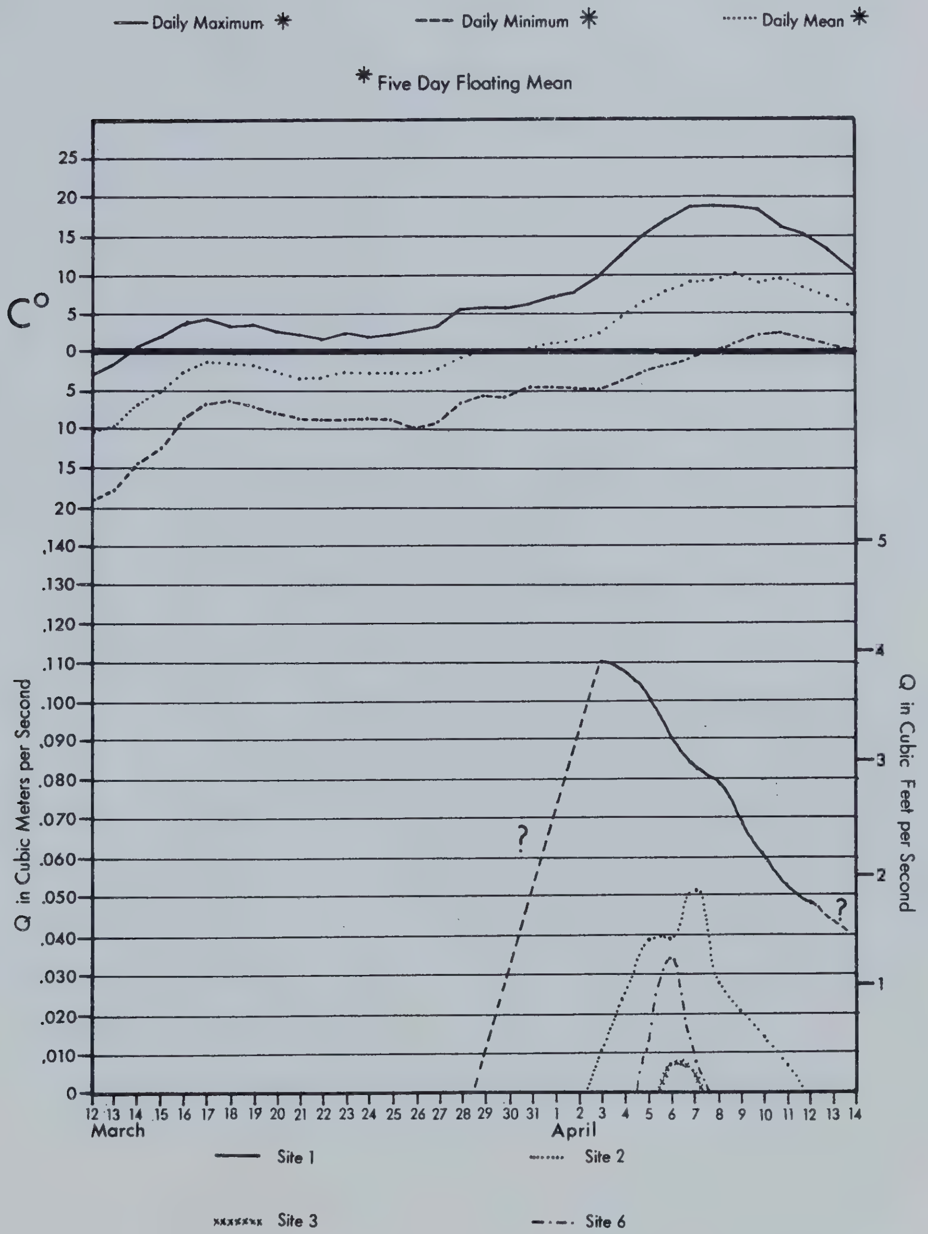
5.9.1 Individual Site Runoff - Site 1 - 107.3 Hectares

On the first trip into the field on April 3, 1976, flow was detected only at Site 1. At that time the measured discharge was .23 cubic meters per second. On subsequent trips into the field, by which time discharge from other sites had begun, flow from Site 1 had begun to decrease in volume. This means that peak discharge at Site 1 was attained on or before April 3 and measurements of total volume of flow could not be made accurately. Using only field data, total discharge was 6.9 hectare meters for an average yield of 6.45 centimeters. It could be estimated that total volume would have been at least 9.8 hectare meters and average yield would have been at least 9 centimeters.

The discharges measured at Site 1 on trips into the field during the melt season show a totally anomalous pattern. Total discharge would have been much higher than at any other site in 1976 as well as from the same site in 1975. There was no evidence of surface outflow

FIGURE 11

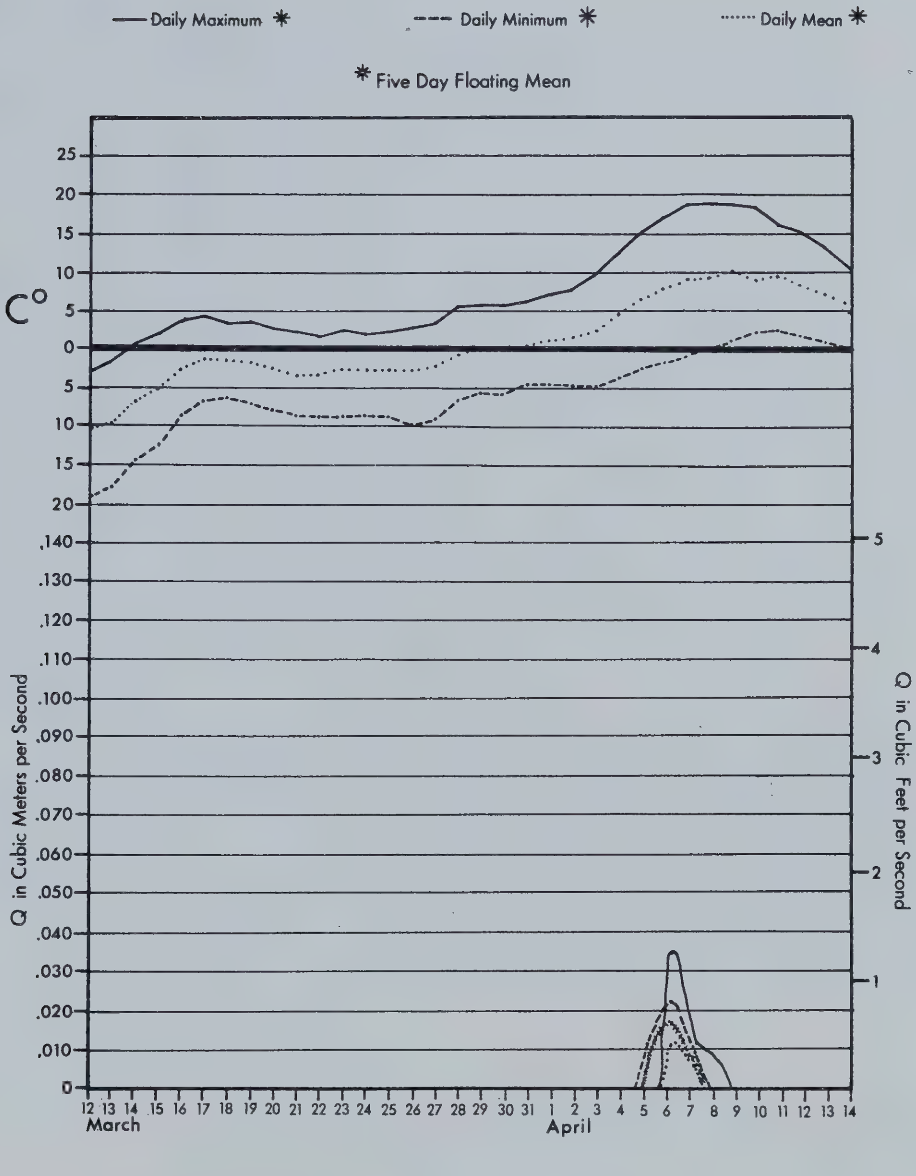
SNOW MELT SEASON
TEMPERATURES AND HYDROGRAPHS
1976



Source: Edmonton International Airport Met. Data

N.B. - Source for Hydrographs - Field observations by author

FIGURE 11
SNOW MELT SEASON
TEMPERATURES AND HYDROGRAPHS
1976



Source: Edmonton International Airport Met. Data

N.B. - Source for Hydrographs - Field observations by author

from Antler Lake. The only possible explanation might be that groundwater flow occurred from the Antler Lake basin very early in the melt season.

5.9.2 Site 2 - 280.1 Hectares

In 1976, Site 2 yielded 2.1 hectare meters of total runoff amounting to 0.7 centimeters of average yield. This was less than one-half the amount measured from the site in 1975.

The 1976 hydrograph of Site 2 flow differs markedly from the 1975 hydrograph (Figure 11). It lacks the second major peak caused when the waters ponded behind the drainage ditch were released. This situation did not occur in 1976 due to the longer melting season. Initial flow was from the adjacent channels, but the large channel drift melted only one day later. Consequently, only one peak is noted on the hydrograph. As in the previous year the evidence of some groundwater flow toward the old slough can be noted by the longer tailing limb of the hydrograph.

Most of the runoff at Site 2 again came from drifts, mainly along the drainage channel and in the areas of low soil moisture storage along the railroad tracks and roadways. There was no evidence of outflow from Wanisan Lake in 1976. If the area above sub-basin 2 in the Hastings Lake basin is included, average yield would be reduced to approximately 0.2 centimeters.

5.9.3 Site 3 - 54.6 Hectares

Runoff was detected at Site 3 at the northeast corner of Hastings Lake on only 2 days at most. It began on April 6 and had ended by April 8. The total volume of flow was .1 hectare meter which was an average of .2 centimeters.

The runoff measured from Site 3 was quite close to the predicted amount in 1976 (Chapter IV, Section 4.4.3). There was very little drifting on Site 3 in 1976. Again, though, most of the runoff came from the areas of low storage near the culvert. There was little evidence of groundwater flow in 1976 at Site 3.

5.9.4 Site 4 - 107.5 Hectares

As in 1975, no runoff was detected at Site 4 in 1976. There was evidence of ponding behind the culvert as in 1975, but none of the surplus water ran off from the site.

5.9.5 Site 5 - 148.9 Hectares

There was no outflow from Sisib Lake toward Hastings Lake in 1976 either. Any surplus waters drained toward Sisib Lake.

5.9.6 Site 6 - 57.0 Hectares

Runoff at Site 6 lasted for approximately 3 days, from April 5 to April 8. The average yield was .8 centimeters and the total volume of flow was .5 hectare meters.

Most of the runoff at Site 6 again came from a large roadside ditch. The maximum average daily flow recorded was .03 cubic meters per second which was greater than the maximum in 1975 but the duration of flow was insufficient to produce a great volume of runoff.

5.9.7 Site 7 - 55.6 Hectares

In 1975, Site 7 had a volume of flow similar to that of Site 6. This was true again in 1976. The duration of flow was 3 days, April 6 through 8. The volume of flow was .5 hectare meters and average yield was .8 centimeters, the same as Site 6.

Although the hydrographs and flow volumes were similar for Sites 6 and 7, volumes were so small in both years that very little can be

said about an absolute relationship between the two.

5.9.8 Site 8 - 29.6 Hectares

In 1976 the average yield from Site 8 in the Joseph Lake basin was .5 centimeters. The total volume was .15 hectare meters. Flow was detected on only two days at most.

The volume of flow in 1976 was twice that of the amount predicted. As in 1975, much of the surplus meltwater came from areas of low soil moisture storage near the culvert.

5.9.9 Site 9 - 284.3 Hectares

The runoff from Site 9 in 1976 was the smallest in terms of average yield of all the test sites at which runoff was measured. This was the same situation as the previous year. Flow was evident only on April 6 and 7 and totaled .4 hectare meters, or .1 centimeter average yield.

As in 1975, the actual measured runoff from Site 9 was less than predicted amounts (Chapter IV, Section 4.4.9). This again was due to loss to percolation because of overland flow. All of the runoff from the fallow field had to travel a long distance to the culvert and most was lost to percolation.

5.9.10 Site 10 - 59.9 Hectares

Test plot number 10 produced only .5 centimeters of average yield in 1976. The total volume was .3 hectare meters and flow was detected on only 3 days.

As in 1975, virtually all of the runoff at Site 10 came from a large roadside ditch. There was little or no runoff from the adjoining fields and no indication of groundwater flow.

5.10 Discussion of 1976 Melt Patterns

The yields of all the test basins in 1976 were generally lower than the previous year (exception was Site 1). This was due to a number of reasons, mainly the melt season. The longer melting season of 1976 allowed a slower thawing of the frozen ground which in turn allowed better infiltration of the snowmelt waters.

Another factor which cut down the amount of runoff was the lesser amount of drifting. In 1975, there were some substantial drifts; however in 1976, drifting was not as extensive, allowing a better distribution of the precipitation.

As in 1975, in nearly all cases the amounts of measured runoff were greater than the predicted amounts (Chapter IV, Section 4.4.1 through 4.4.10). The exceptions again were Site 9 and Sites 4 and 5 at which runoff was lost to depressional storage.

Section 5.12 will be a comparison of the two melt seasons and will include a more detailed discussion of the 1976 melt season.

5.11 Water Quality

As a supplement to the study, water quality samples were taken during the 1976 runoff season. The original intent was to take several samples through the melt season to ascertain the change in quality over the duration of the melt. The 1976 melt season severely hampered the collection of necessary data, however. At many sites, flow was evident for only two days. Nevertheless, samples were obtained from four of the sites and an analysis of the water quality follows. The water samples were analyzed by the Department of Zoology, University of Alberta water chemistry laboratory. The results of this analysis are presented in Table 5.

TABLE 5

WATER QUALITY DATA

Site	pH	Alkalinity as $CaCO_3$ Phenl mg/l	Alkalinity as $CaCO_3$ Total mg/l	Conductn. micromhos	Total Residue mg/l	Iron mg/l
1	7.33	0	168.0	388	390.3	0.70
2	6.70	0	49.2	280	342.6	0.85
7	6.83	0	38.8	168	173.0	0.15
9	7.06	0	61.2	152	173.3	0.17

Site	Chloride mg/l	Color	Turbidity JTU	Sulfate mg/l	Sodium mg/l	Potassium mg/l
1	6.00	150	4.5	62	16	16
2	4.37	437	7.0	136	3	19
7	2.73	290	4.0	61	3	10
9	6.00	343	3.6	14	8	12

Site	Total PO_4 mg/l	Ortho PO_4 mg/l	Meta & Poly PO_4 mg/l	Organic PO_4 mg/l	Silica mg/l	Ttl Kjld Nitrogen mg/l
1	2.02	1.11	0.61	0.30	14.3	3.21
2	1.96	0.73	0.81	0.42	3.40	3.90
7	1.76	1.06	0.40	0.30	3.08	1.72
9	1.88	1.12	0.38	0.38	3.20	1.59

Site	NH_3-N mg/l	Organic Nitrogen mg/l	NO_3-N mg/l	NO_2-N mg/l	Hardness as $CaCO_3$ Calcium mg/l	Hardness as $CaCO_3$ Total mg/l
1	0.36	2.85	0.17	0.002	122	212
2	0.50	3.40	0.14	0.009	88	120
7	0.84	0.88	0.13	0.009	54	80
9	0.18	1.41	0.09	0.004	38	64

* Samples were taken on April 8, 1976

Six physical properties of the water were tested. These six were pH, alkalinity, electrical conductance, turbidity, hardness and color. The pH is a measure of the hydrogen ion concentration. A value of seven indicates neutral water. Lower values indicate water that is acidic while values greater than seven indicate water that is basic. According to the Alberta Surface Water Criteria, acceptable values are between 6.5 and 8.5 (Lake Wabamun - Present Water Quality, 1970).

Alkalinity refers to the ability of water to neutralize acid. It is usually referred to in terms of amounts of calcium carbonate.

Electrical conductance refers to the ability of the water to conduct electricity. The values for electrical conductance depend on the concentration of ionized mineral salts in solution.

Turdibity measures the ability of suspended material in the sample, such as organic matter, clay, silt or other particles to diminish the penetration of light through the sample. The values for turbidity are expressed in terms of Jackson Turbidity units.

Hardness, like alkalinity, is reported as an equivalent amount of calcium carbonate. Hardness is due to the presence of calcium, magnesium and other alkaline earth metals in the water.

Color is the result of many things in water. It is mainly due to the presence of organic compounds, such as humus, from leached decaying vegetation, waste effluents or metallic ions such as iron. True color (measured here) is measured by reflectance, while apparent color is merely the visible color.

Several chemical properties of the snowmelt water samples were also analyzed. Sodium is abundant in nature and is readily soluble in water. It is usually found in sewage, industrial wastes, oil field drainage and

evaporite sediments. High amounts can be injurious to man and aquatic life (Powell, 1964).

Potassium is similar to sodium in many ways, but is generally found in lesser concentrations. It is necessary for plant growth in fairly large amounts.

Iron, too, is a cation (positively charged) that is found in natural waters. It is necessary for plant growth in small quantities and the Alberta Surface Water Criteria lists a maximum value of 0.3 milligrams per liter as safe.

Silica is a non-ionic compound found in natural waters. It comes from silicate rocks and generally has values in natural waters of less than 40 milligrams per liter (Powell, 1964). It is necessary, too, for growth, by some plants.

Phosphates are a form of nutrient found in lake waters which are necessary for plant growth. The plants use the phosphorus from the negatively charged phosphate ions. The most easily assimilated forms are the orthophosphates (Kramer, et. al., 1972). High concentrates of phosphate ions can be found in waters draining agricultural areas or waters which receive raw sewage. The Alberta Surface Water Criteria recommends phosphate loadings of less than 0.15 milligrams per liter.

Another plant nutrient, nitrogen, is found in nearly all natural waters. The major source of nitrogen (NH_3 and NO_3) is runoff from agricultural areas and sewage. According to Alberta Surface Water Criteria, values of less than 1.0 milligram per liter are acceptable.

The water qualities of the individual lakes of the moraine have been discussed quite completely in the reports that have been previously done regarding the study area (EPEC, 1971, Stanley and Asso-

ciates, 1974, Shelly and Associates, 1975). The general pattern is that the lakes in the southern part of the moraine are higher in dissolved solids. In lakes such as Miquelon this high percentage of dissolved solids has hindered the production of algae somewhat. The lakes of the northern portion of the moraine exhibit lower amounts of dissolved solids, but nutrient levels needed for plant growth are still higher.

Currently, there are serious problems concerning lake water quality in all of the lakes of the moraine. The problems are directly related to the advanced eutrophic state of the lakes. With this in mind, most of the attention in the discussion of water qualities will concern the addition of nutrients.

The effect of atmospheric nutrient loadings in the Cooking Lake moraine has been discussed in a thesis done in the Division of Meteorology, Department of Geography, University of Alberta, by Roger Caiazza (1976). In the thesis he discussed the amount of nutrients added by all forms of precipitation in a much more complete review than could be presented in this study. However, the author will attempt to discuss the effects of snowmelt runoff on water qualities of the lakes of the moraine.

In the case of all four samples, pH was near normal. The extreme values found (6.70 at Site 2 and 7.33 at Site 1) were within the criteria established by the province. Color ranged between 150 and 437 units and while these figures were greater than reported values for limiting water based recreation activities (Stanley, 1974), they are not out of line with other figures recorded from the area (Erxleben, 1972). Turbidity was low at all four sites. Alkalinity and hardness

at Sites 2, 7 and 9 were also quite low; however, at Site 1 they were quite high. This was probably reflective of the slough water and although the values were high, they would not seem to be a major deterrent for water based recreation.

The dissolved solids, potassium, sodium and iron, follow a pattern similar to alkalinity and hardness. All three are found in higher concentrations from the Cooking and Hastings Lake sites than from the Joseph Lake sites. The same is true for the anions chloride and sulfate. The significance of these findings is discussed in a paper by Drs. F. W. Schwartz and D. N. Gallup (1976). In general, it could be said that one of the reasons for these concentrations is the contribution of groundwater. Silica levels as well were much higher at Site 1 than the other three sample locations.

As stated previously, the most critical factor of the water quality of the snowmelt runoff is the extent to which nutrients will be added. The main nutrients are phosphorus, found in the form of phosphate (PO_4), and nitrogen, found in the form of ammonia (NH_3), and nitrate (NO_3, major source). Phosphates are broken down into three groups, orthophosphates, which can be easily used by plants, meta- and polyphates and organic phosphates. The values for each of these can be found in Table 6. In all cases, the values for phosphates are extremely high. The values for orthophosphates, with the exception of Site 2, are all over 1 milligram per liter. This compares with area values of from .20 to .40 milligrams per liter found for total phosphates by Erxleben (1972). These values are far in excess of the standards established by the province of less than 0.15 milligrams per liter. Water quality measurements taken in 1970 (EPEC, 1971) show the total phosphate measurement

for lake water to be 1.8 milligrams per liter. While this value has probably increased, it can still be seen that the quality of snowmelt samples taken is very poor with respect to phosphates. The amount of phosphate loading necessary to produce algal blooms differs with algae type; however, studies have shown that in some cases as little as .010 milligrams per liter of phosphate are sufficient to cause algal blooms (McCaull and Crossland, 1974). It should be noted that the snowmelt runoff water that was sampled represents runoff from late season melting. The 1976 snowmelt season produced very little runoff and the runoff which was sampled would be equivalent to very late season runoff in a normal year. Because of this, low quality could be expected.

The amount of usable nitrogen (NH_3 and NO_3) necessary to produce algal blooms also varies with the species of algae. Compared to lake samples (EPEC, 1971) both the levels of nitrate and ammonium are below those found in the lake water. The values found from the snowmelt samples of 1976 were also below the limiting nitrate levels given by Alberta Surface Water Criteria. The nitrogen levels are not as alarming as phosphate levels; however, they are high enough that they could definitely contribute to algal growth.

With respect to nutrient loadings, it can generally be said that the snowmelt runoff of 1976 was of poor quality. It should be restated, though, that because of the small volume of runoff, the melt water was equivalent to late season runoff in a normal year. This water is of poor quality because in many cases it has percolated into the soil and reached drainage channels as interflow. In the process, nutrients are added from agricultural areas that have been fertilized, feedlots with animal waste and possibly from the sewage of lakeshore

developments. In a year of normal or above average precipitation, it is estimated that the water from initial melting is of high quality and could be used to supplement lake levels without adversely affecting quality.

5.12 Comparisons of 1975 and 1976 Melt

Conditions prior to the snowmelt seasons of both 1975 and 1976 were very similar. In both cases the last half of the preceding summer was extremely dry and these conditions severely depleted soil moisture storage. The amount of snowfall in both winters was well below normal and in both years the total winter precipitation was inadequate to recharge all soil moisture levels completely. The runoff amounts actually measured in each year differed greatly.

The 1975 runoff season was very short. Temperatures remained relatively cold until the middle of April and then warmed up rapidly. This rapid warming caused the snowpack to ripen and run off quickly, exceeding the infiltration rates of the still frozen ground. This was the cause for the greater than expected amounts of runoff which were measured. In addition, there was evidence of groundwater flow carryover from previous wet years. As mentioned previously, 1972, 1973 and 1974 were years of above average precipitation. Because of this series of wet years there was a considerable amount of groundwater flow toward the lakes. A portion of this groundwater flow was still evident in the flow recorded from some of the test sites.

The meteorological factors (temperature, precipitation and air masses) of the melt season of 1976 were much closer to those of a "normal" melt season in the Edmonton area. Daily maximum temperatures rose above freezing shortly after the first of March. Daily maximums stayed

above freezing and rose slowly while daily minimum temperatures remained below freezing until April 8. This lengthy cycle of daily thawing with nightly freezing allowed for a slow ripening of the snowpack and runoff rates which more closely coincided with the infiltration capacities of the thawing ground.

5.13 Possible Sources of Error

As with any study of this sort, a certain amount of error is inherent. Care was taken so that error was minimized in most cases; however, with such a large number of variables, complete accuracy is impossible.

The major source of error is in the measurement of runoff. There is always variation in the daily runoff due to diurnal fluctuation. It was impossible, due to time constraints, to gauge each site a number of times daily to establish absolute patterns. Instead, corrections were made to the daily flow measured for temperature, cloud cover, wind, insolation and the amount of surface detention storage to arrive at the average daily flow figures.

Also, as mentioned earlier, in the runoff flows measured it is difficult to differentiate between groundwater flow and snowmelt runoff. At some sites it was obvious that the total volume and duration of flow were affected by groundwater flow. This could be expected since most of the sub-basins used were in the lower parts of the tributary basins of the lakes. Because of this some groundwater flow toward the main lakes would show up at these sites. Since it is impossible to determine the exact extent, though, this must be listed as a source for error.

Finally, the topographic boundaries of the sub-basins above each

gauging site were marked using air photographs along with field observations. Although care was taken to delineate the boundaries accurately, slight errors could cause differences in the amounts of runoff per unit area.

A certain amount of error is to be expected in studies of this nature. However with close attention to details and slight adjustments where they are found necessary, error can be minimized.

5.14 Drainage to Lake Area Ratios

The final average yield figures for the sub-basins, although they are not greatly in error, can be misleading if they are used to interpret area patterns. It has been stated several times previously that much of the drainage in wet and average years is into depressions from which there is no outflow. This effectively reduces the size of the drainage basin of each of the lakes.

The drainage sub-basins gauged in this study in nearly all cases had direct drainage toward the lakes. It should be restated that these were sub-basins and in years of above average precipitation they would have received flow from sub-basins above them still in the drainage area of the same lake. For example, sub-basin number 2 is in the Hastings Lake basin. In both field seasons of this study it drained an area of approximately 280 hectares. In wet years, though, it would receive drainage from the overflow of Wanisan Lake and other areas north of the Site 2 sub-basin. The same is true for the sub-basin gauged at Site 1. If the areas north of the sub-basin which drain through the site into Cooking Lake are included the drainage area would increase to over 2000 hectares. This would decrease the average yield figures.

The conditions are different for a wet year. The best example of wet year drainage is 1974. The meteorological conditions in 1974 have been discussed previously in the thesis. It was a year of major surpluses and the lakes showed accordant rises. In 1974 the Whitemud Creek basin showed a spring runoff total of 4663 hectare meters which amounted to an average yield of 13.8 centimeters. Table 3 shows the accordant rise of Cooking Lake and the approximate surpluses and drainage to lake area ratio. The total basin yield in 1974 would have been 10.4 centimeters, slightly lower than the area average. This would have allowed for some filling of local depressions by runoff waters, however, there was probably outflow from all local depressions toward the main lakes. It is for this reason that probable drainage to lake area ratios are listed as near maximum.

From this data and field observations, conclusions were drawn about the drainage to lake area ratios of the moraine. After a series of wet years it appears that nearly the entire basin contributes runoff to the main lakes. The depressions are filled and outflow from them is directed toward the main lakes. In the case of Cooking Lake, the maximum drainage area is approximately 5 times the lake area. The results of yearly surplus and deficiency patterns on lake levels with varying drainage areas are presented in a paper by Laycock (1973). This major inflow is much more noticeable in Cooking Lake where even the final lake level is below the old outflow level. In years of above average precipitation, Hastings Lake would have a drainage area eleven times the lake area (Table 2). Since the level of Hastings Lake has remained near outflow levels in recent years, part of this major surplus flows out of the lake in Hastings Creek, thus keeping the level fairly well

regulated.

In a dry year, the patterns are much different. As observations from the field season show, the only subdrainage basins which contribute to the lake are those immediately adjacent to the lake or areas which have artificial drainage. In the Cooking Lake basin, this would limit the size of the actual contributing area to, at most, an area again as large as the lake. Again, these patterns for different lake drainage areas are shown by Laycock (1973). The drainage area of Hastings Lake has been effectively enlarged even for dry years. The artificial drainage has included depressions which would not have contributed in dry years and now even in these years of below average precipitation the drainage area to lake area ratio might still be approximately four or five to one.

5.15 Water Balance Patterns

When one analyzes the snowmelt runoff patterns exhibited for the sub-basins studied, certain expected patterns do show up. One example is in the comparisons of Sites 6 and 7. They are sub-basins of comparable size and somewhat similar land use. In both field seasons the amount of runoff from each site was very nearly equal. This represents greater than expected runoff from Site 7, probably due to increased drifting around the edges of the forest openings. The hydrographs differed as expected. Runoff from Site 6 took place over a shorter period of time and had a greater peak flow due to the fact that the land was mainly in agricultural use with less forest cover to prolong melting. At Site 7 the hydrograph was flatter due to slower melting in the forest areas. However, when compared with Site 10, the expected patterns failed to hold. It is a sub-basin nearly the same size as

Sites 6 and 7 completely in agricultural use. It was expected that Site 10 would yield more runoff than either Site 6 or 7 due to the lower soil moisture storage capacities for arable and pasture lands (i.e., less runoff needed for soil moisture recharge). In both field seasons, however, the opposite case was true. Runoff measured at Site 10 was lower than that measured at either Site 6 or Site 7.

The preceding discussion shows the problems of trying to make snowmelt runoff predictions in years of below average precipitation. It is inaccurate to describe a flow lasting 13 days with a peak flow of .05 cubic meters per second (peak recorded flow, Site 6, 1975) as "flashy" just as it is to say that a hydrograph lasting 15 days with a peak recorded flow of .04 cubic meters per second (Site 7 in 1975) shows a forest influence. Because of the below average amounts of snowfall in each of the field seasons, it is impossible to make an accurate assessment on the effect of differing land uses on the amount of snowmelt runoff, except for dry years.

5.15.1 Drifting

Although little can be ascertained about the effects of land use on the amount of snowmelt runoff in average and wet years, much can be learned about other aspects of the water balance of a basin. The major factor which can be seen is the contribution of drifting in below average snowfall winters. In both field seasons, winter precipitation was inadequate to recharge all soil moisture storage levels. In both years though, there were surpluses coming mainly from drifts. In some cases, drifting makes a significant contribution to total runoff where there might normally be no flow (Sites 6 and 7, 1975). What effectively happens to the water balance with excessive drifting is that precipitation

amounts are decreased in much of the area and the increases in drift areas are seen directly as runoff. As an example, if the normal yearly water balance for an area was (in cm)

$$\begin{array}{ccccc} P & PE & D & S & SC \\ 45.0 = & (52.5 & - 11.25) & + 3.75 & \pm 0 \end{array}$$

the change in an area from which snow had drifted might be:

$$45.0 - 5.0 = (52.5 - 12.5) + 0 \pm 0$$

Conversely, the water balance of an area which experienced drifting would be:

$$45.0 + 5.0 = (52.5 - 11.25) + 8.75 \pm 0$$

A greater effect might be seen in a year in which there was no average surplus. Such a year might be represented in this manner:

Average	42.5	$= (52.5 - 10) + 0 \pm 0$
Area from which snow has drifted	$42.5 - 5.0$	$= (52.5 - 15) + 0 \pm 0$
Drift areas	$42.5 + 5.0$	$= (52.5 - 10.0) + 5.0 \pm 0$

The occurrence of groundwater flow is also evident at least in the 1975 field season. Several sites show evidence of groundwater flow toward the major lakes of the moraine. Following a series of wet years, the contribution of groundwater is noticeable (Sites 1, 2 and 3, 1975); however, in the following year the flow of groundwater is negligible with the possible exception of one site (Site 1). A decline in the volume of groundwater flow was noticed after one dry year. After a series of dry years it would be expected that the amount of groundwater flow which would be evident in snowmelt flows would be virtually negligible. In drier years, much of the snowmelt which might normally have gone to recharge groundwater levels never makes it to the groundwater table. It is instead held in soil moisture storage and consumed

by vegetation from storage.

Also with respect to groundwater and its relationship to snowmelt runoff, it would be expected that after a series of dry years, even in a year with above average surpluses much of the snowmelt which might ordinarily go to runoff and be directed toward the lakes, would be used in groundwater recharge. The beginning of this pattern could be seen in 1976 after only two dry years, and the situation would probably be more evident in a wet year after a series of dry years.

5.15.2 Hastings Lake Basin

Another pattern of the water balance which becomes more understandable is the anomalous balance of the Hastings Lake basin. As mentioned previously, while all of the other lakes in the moraine have declined steadily in level since the early 1950's, the level of Hastings Lake has remained quite constant. Some of the reasons for this become evident with careful examination of the field data.

Using the data from 1975, spring surpluses due to snowmelt from all of the study basins in the Hastings Lake basin averaged a greater yield than either the Whitemud or Vermilion River basins. Runoff from the Joseph Lake sites were less in average yield than either the Whitemud or Vermilion basins. It must be re-emphasized that the field data taken was not collected in a year of normal precipitation and any conclusions drawn about the patterns should not be regarded as being the pattern in a normal year. It is significant to note, however, that even in a year of below average surplus, areas within the Hastings Lake basin show surpluses which are above the regional averages. The possible reasons for the greater than average surpluses shown in the field seasons and for the continued high level of Hastings Lake can be attri-

buted to a number of factors. A discussion of these factors will show the effect of watershed change on water balance.

The Hastings Lake basin has undergone considerable clearing. The reason for most of this clearing has been so that more land can be put into agricultural production. In many cases, along with clearing, the areas have been artificially drained for use as pastures or hay meadows. Although this has been done in other lake basins, it has been most effective in the Hastings Lake basin north of the lake. These changes have affected the water balance in several ways.

The most obvious effect is the change in soil moisture levels. In changing from forest to pasture, the soil moisture storage values change from 25 centimeters to 15 centimeters. Grain crops can utilize 10 centimeters of soil moisture compared to 25 centimeters for forest cover. This effect is obvious. Over a long period of years, surpluses occur much more frequently at the 10 and 15 centimeter soil moisture storage levels than at the 25 centimeter level (Appendix I).

The major effect caused by the change from forested land to agricultural comes from improved drainage. One of the reasons suggested to explain lower lake levels in Central Alberta is the ratio of drainage area to lake area (Laycock, 1973). This case is certainly true in the Cooking Lake moraine. While drainage areas appear large for some of the lakes in the moraine, these figures can be misleading. In many years there is inflow into the small sloughs in some of the basins but no outflow toward the main lake. In most cases, the small lakes or sloughs act as evaporation basins for the inflow waters.

In the Hastings Lake basin there is evidence of artificial drainage to assist normal drainage toward the lake. Sub-basin 2 is an

example of this type of artificial drainage. A fairly large slough which is evident even on recent topographic maps was drained for use as a hay meadow. After drainage, areas which used to contribute water only to the slough, now drain all the way to the lake. As shown in the runoff data earlier in the chapter, there is also evidence of groundwater flow toward Hastings Lake during spring snowmelt and probably during other times of surplus precipitation as well. The effect of artificial drainage is to increase the ratio of drainage area to lake area.

5.15.3 Phreatophytes

Also associated with clearing and artificial drainage for agricultural areas is the removal of phreatophytic vegetation. Phreatophytes, in arid areas, are strictly defined as being plants that grow where they can send their roots down to the water table to obtain supplemental water for transpiration (Meinzer, 1927, Robinson, 1952 and 1958). In Alberta phreatophytes can be defined as being plants which use more water than is directly available to them from precipitation (Laycock, 1968). This includes groundwater sources, but may also include surface water flows (depression storage and riparian supplies).

Phreatophytes are common in areas of hummocky disintegration moraine in the Prairies (Meyboom, 1962, 1964) and are usually found ringing the depressions mentioned earlier. Here they are able to supplement their water supply and transpire at a rate that is equal to or greater than the potential evapotranspiration rate. In times of adequate precipitation, the transpiration rate would approximately equal potential evapotranspiration. During dry periods, however, advected heat from dry areas is available and thus phreatophytes will transpire

at a rate greater than potential evapotranspiration. Laycock (1968) found that a value of potential evaporation + ½ deficit closely approximated phreatophytic evapotranspiration during dry periods. This value can also be used to estimate small lake evaporation and irrigated crop use.

When sloughs were drained to begin agricultural production and the areas around them were cleared, it was usually phreatophytic vegetation which was removed. Using the information presented earlier (Chapter II, Section 2.15), it can be suggested how much available moisture could be directed toward the lakes if phreatophytic vegetation was removed. The possibility of phreatophyte removal to supplement lake levels will be discussed more fully along with other alternatives in the following chapter.

The patterns of clearing have also influenced the water balance in several areas. In most places, areas were not clear cut. Pastures or fields were generally cleared in flatter areas, while trees were left on higher areas or steeper slopes where cultivation was not feasible (Site 7). Often rows of trees were left as windbreaks. These cutting patterns influenced the accumulation of snow. Many studies (Connaughton, 1935, Wilm and Collet, 1940, Anderson, 1956, Swanson, 1972) have shown that snow accumulation and melt is greater in open areas surrounded by trees. Swanson (1972) shows greater accumulations and melt from openings in forest cover in Alberta on rangeland sites. Witter (1976) shows the greater accumulations of snow around forest edges in the Cooking Lake moraine. Management of a snow cover in this fashion is generally utilized to produce a more desirable regime, but in some cases it can be used to produce desired increases in snowmelt. Is is

possible that the clearing patterns in the Hastings Lake basin have produced greater spring snowmelt runoff.

The Hastings Lake basin may also have advantages because of drainage from higher terrain south of the lake. Here, precipitation could be fractionally higher and evapotranspiration amounts lower because of the great amount of north facing slopes. Also, much of the land is fairly well drained so there is less loss to depressional storage and phreatophytes.

The Joseph Lake basin shows much lower yields than the Hastings Lake basin. This is attributable to several factors. First, the drainage area to lake area ratio is much smaller than for the Hastings Lake basin (Table 2). Although the land is more rolling and somewhat better drained, there is still some loss to depressions which decreases the ratio.

There has been a considerable amount of clearing for agriculture in the Joseph Lake basin. Along with this, soil moisture storage values were reduced. This adds water to the lake in years of surplus. With the clearing and the more moderate terrain of the Joseph Lake basin, however, there is less opportunity for drifting. Because of this, in years of below average precipitation, and more specifically snowfall, the more even distribution of snowcover allows a better possibility for recharge in all areas.

5.16 Summary

In this chapter, the snowmelt patterns for the field seasons of 1975 and 1976 have been shown. Because precipitation and melt conditions in both years were below normal, it is difficult to make accurate correlations between land use and its effect on snowmelt runoff that

would apply in average and wet years. The existing patterns were shown, though, and an attempt was made to explain some of the water balance patterns of the moraine, especially the Hastings Lake basin.

While some suggested explanations were made as to how watershed management practices have changed the water balance of the Hastings Lake basin, the next chapter will include a discussion of other possible water management alternatives for the Cooking Lake moraine.

CHAPTER VI

WATER SUPPLY ALTERNATIVES

6.1 Introduction

Since the initiation of the provincial government's study on the Cooking Lake moraine area, a number of different methods have been proposed for supplementing lake water supplies. The first study done by EPEC Consulting Ltd. suggested that the only reliable method of water supply was importation of North Saskatchewan River water. Subsequent studies (Stanley and Associates, 1974, Shelley and Associates, 1975, EPEC, 1976) have suggested other possible means of supplementing water supply, including internal water management by improving drainage toward the major lakes (Stanley, 1974), transfer from nearby basins such as Bittern and Coal Lakes (Shelley, 1975) and forest cover management to increase yields from snowmelt. It is felt by some, however, that since the initiation of the studies, the major emphasis has been upon importation with little attention being given to the other possible alternatives. This chapter will be a review of some possible water supply alternatives.

6.2 Interbasin Pumping

As mentioned previously, the major schemes for supplementation of water levels have involved importation of water from the North Saskatchewan River. The North Saskatchewan has been selected since it is the only "reliable" source of supply. It had been felt that stabilization of lakes at an optimum level should be undertaken. In a recent study, however, it has been shown by EPEC Consulting Ltd. (1976) that in many cases a fluctuation in level of two to three feet every two to

four years may be desirable to limit algal growth and stimulate waterfowl production. To provide for this required fluctuation, EPEC Ltd. has proposed extensive engineering structures to regulate lake levels.

If a fluctuation in lake levels is desired, it is felt by the author that a "reliable" source of supply is not necessary. The same objectives might still be accomplished by pumping, but to a lesser degree. The pumping could be from neighboring basins which have occasional yearly surpluses. One such area where surpluses are available in many years, adjacent to the moraine area, is the Little Hay Lake basin.

The Little Hay Lake basin is located southwest of the Miquelon Lakes (Figure 12). The Little Hay Lake basin is the site of one of the largest agricultural drainage projects in the province. The area has undergone a considerable amount of ditching to remove excess water and now drains to the southeast through ditches (Plate 9) and natural channels, eventually getting to Camrose Creek. The actual drainage area including drained lands is approximately 90 square kilometers.

In some springs the problem of disposal of snowmelt runoff is a major one. One possibility for the disposal of surplus flow would be to pump some of the excess over the low divide into upper Miquelon Lake.

One of the small streams tributary to the main creek in the lower end of the Little Hay Lake basin has its headwaters in a slough near the Little Hay Lake - Miquelon divide. From this slough there is an artificial drainage ditch which runs into the rest of the drainage system (Plate 10). This artificial channel has a shallow gradient and with a minor amount of pumping or perhaps only ditching, the flow could

FIGURE 12

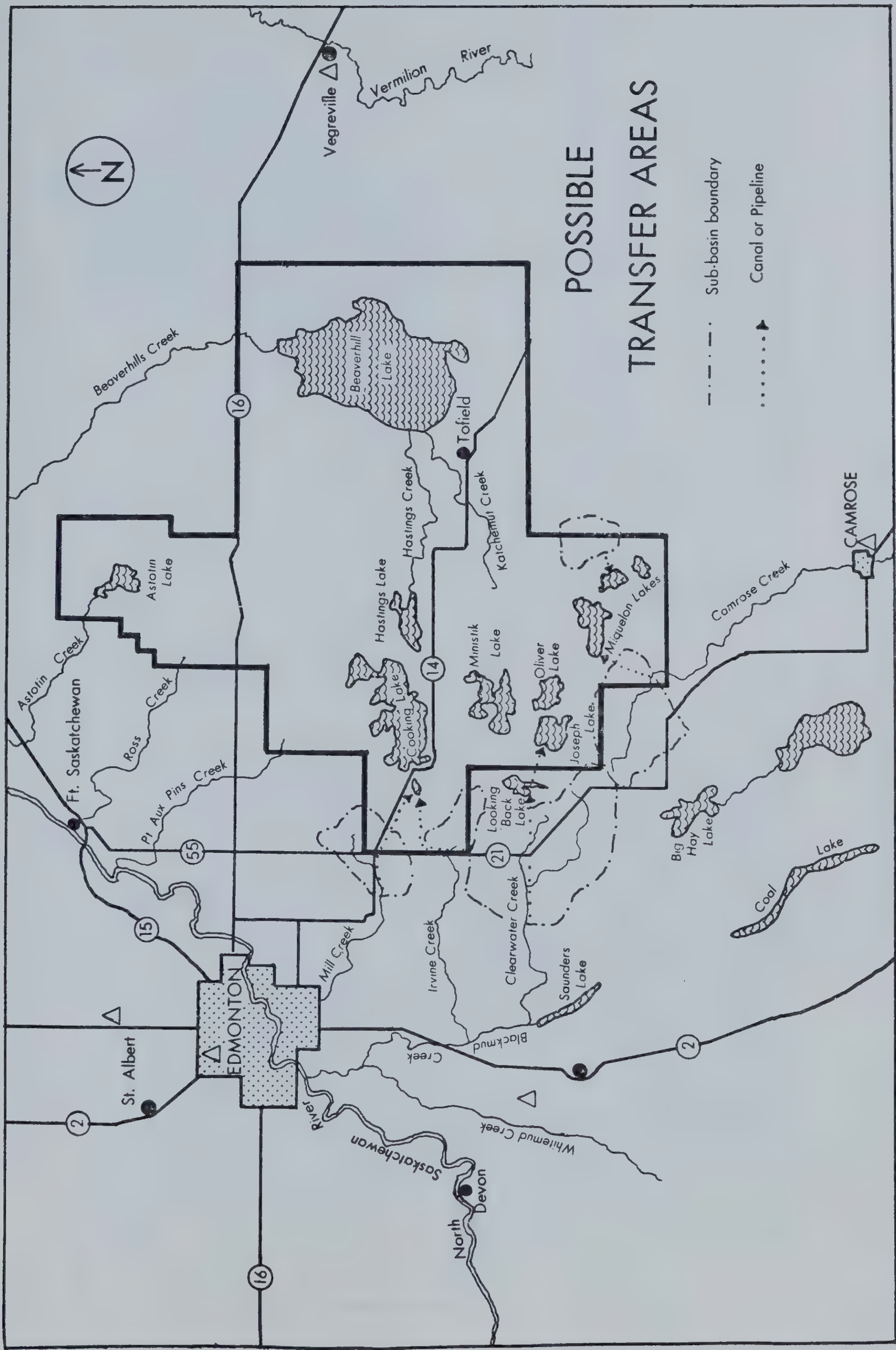

POSSIBLE
TRANSFER AREAS
Sub-basin boundary
Canal or Pipeline
N
Vegreville
Vermilion River
Beaverhills Creek
Beaverhill Lake
Tofield
Hastings Creek
Katchemut Creek
Hastings Lake
Cooking Lake
Ministik Lake
Oliver Lake
Miquelon Lakes
Joseph Lake
Looking Back Lake
Astotin Lake
Astotin Creek
Ft. Saskatchewan
Ross Creek
Pt Aux Pins Creek
Camrose Creek
CAMROSE
Big Hay Lake
Coal Lake
Clearwater Creek
Irvine Creek
Mill Creek
Saunders Lake
Blackmud Creek
Whitemud Creek
EDMONTON
St. Albert
North Saskatchewan River
Devon
16
14
55
21
15
2

FIGURE 12

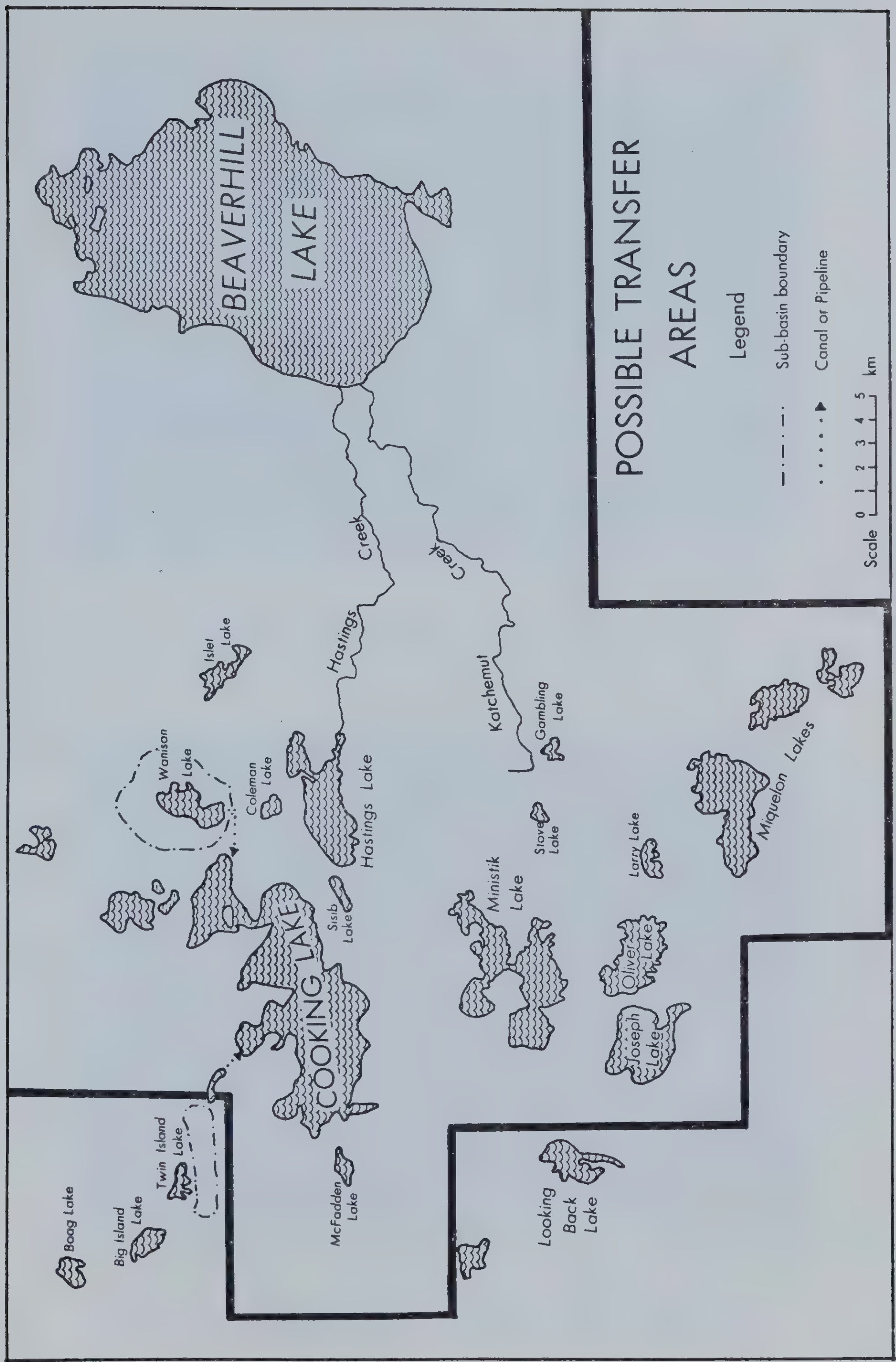

POSSIBLE TRANSFER AREAS
Legend
Sub-basin boundary
Canal or Pipeline
Scale 0 1 2 3 4 5 km
BEAVERHILL LAKE
Hastings Creek
Katchemut Creek
Islet Lake
Wanisan Lake
Coleman Lake
Hastings Lake
Gambling Lake
Stove Lake
Miquelon Lakes
Larry Lake
Ministik Lake
Sisib Lake
COOKING LAKE
Oliver Lake
Joseph Lake
Looking Back Lake
McFadden Lake
Twin Island Lake
Big Island Lake
Boag Lake

PLATE 9

Artificial channel draining Little Hay Lake

PLATE 10

Small artificial channel draining a slough in Little Hay basin near Miquelon divide. Flow could be reversed with slight ditching to facilitate transfer.

be reversed and the possibility for diversion could exist. If runoff waters were diverted at this point, the drainage area would be 77.2 square kilometers.

To explore the feasibility of transfer from the Little Hay Lake the author spoke with Mr. Delvin Brosz, an engineer with the South Dakota Department of Natural Resource Development, and Morris Irrigation, Ft. Pierre, South Dakota. Portable pumps which might be used for a system of this type are manufactured by the Berkely Pipeline Company. The pumps are centrifugal and there are models capable of delivering over 1500 U. S. gallons per minute (3.5 cfs) to heads of over 40 meters. Centrifugal pumps of this sort are most feasible for a system of this type as they are capable of delivering moderately large volumes of water to a greater head than turbine or propeller pumps.

To accompany a pump of this type, plastic pipe, such as the type used in irrigation systems could be used. A thirty centimeter plastic pipe would adequately handle the volumes of flow which would be pumped. The plastic pipe would also allow simple installation and transportation when necessary.

Pumps like the ones mentioned here would cost in the range of $4,000 to $5,000. The plastic pipe for such a system would cost approximately $6.00 per foot including all necessary couplings.

As previously mentioned, most of the Little Hay Lake basin is in agricultural use. The drainage that has taken place has allowed grain crops to be grown so that now, much of the area has a 10 centimeter soil moisture capacity. It can be seen from the water balance tables of the area (Appendix I) that in many years there is no surplus at the

10 centimeter storage level. However, when there is surplus, the total volume from the Little Hay Lake basin would be enough to add significantly to the lake levels of the Miquelon Lake (#1).

Table 6 shows the amounts of water that would have been available for transfer in recent years. These figures were arrived at using area streamflow data. Rather than using strictly soil moisture storage calculations (yearly spring surplus), data from the Whitemud Creek were used (from Table 4). It was assumed that the average yield from the Little Hay Lake basin would closely approximate that of the Whitemud basin. While the actual yields might be somewhat higher in the Little Hay basin (due to less loss to depressional storage), these figures should be a reasonable estimate.

If the entire amount of surplus was to be transferred the effects on lake levels would be significant. In 1972, a year of near average surpluses, the total volume of surplus was 313 hectare meters. With a surface area of 737 hectares (EPEC, 1976) this amount of water would add .4 meters to the level of the lake. In 1973, the surplus of 192 hectare meters could add .26 meters to lake levels and in 1974, a year of extreme surpluses, the total yield of 1062 hectare meters would add 1.4 meters to the level of the lake.

It should be pointed out that these volumes are absolute maximums and tha total volume of water which could be used for transfer will be reduced due to several factors. If water was to be pumped using the pumping system previously mentioned, some sort of surface detention storage would have to be provided. The pumping rate of approximately

.16 cubic meters per second would most likely be exceeded by inflow. In this case, surface detention by enlarging a slough to hold the water which would pond up would be necessary. If this was the case, there would be evaporation losses from the ponded water. The exact amounts would vary, of course, due to winds, temperature, etc.

Perhaps the major factor leading to the reduction of the total amount of transferable water would be water quality. Because of the quality of the lakes in the moraine, excessive nutrient loadings from the snowmelt water would severely compound the serious problem of eutrophication. While other area studies (Erxleben, 1972) have shown that early season snowmelt water quality is relatively good, this study found that late season flows or flows in years of low surpluses are extremely high in nutrients, specifically phosphates and nitrates. This problem could be even more evident in the agricultural land of the Little Hay Lake basin which would certainly yield high amounts of nitrogen and phosphates. Because of this, it is felt by the author that if water was transferred, only early season flows of snowmelt should be allowed to be transferred. This might cut total volume by as much as one-half or more, but excessive nutrient loadings could be disastrous. It might be suggested that constant monitoring of water quality should be instigated if water is to be transferred. In this way it would be possible to cut off transfer when nutrient levels become excessive.

A critical value for nutrient loading should be determined by research in the moraine area by Dr. D. N. Gallup of the University of Alberta Department of Zoology.

A scheme of transporting water via a portable pipeline, such as the one mentioned here, would have several advantages over a major project such as the pipelines suggested by EPEC Consulting Ltd. (Chapter III). The main advantage would be in comparative cost. For transfer to Miquelon Lake from the Little Hay Lake basin, approximately 200 meters (6888 feet) of pipe would be needed. At a cost of $6 per foot of pipe, the cost for pipe would be $41,328. The pump required to move the water retails for $4,614. The yearly cost for energy (at 2.5 cents per kilowatt hour for two months) would be $1584 per year. At these costs, water could be pumped for ten years at a cost of approximately $60,000. Certainly other costs such as installation, maintenance, depreciation and right-of-way costs where the pipe could not be laid in roadside ditches, would have to be figured. In any case, however, total costs would still be much lower than the $7.7 million pipeline system suggested by EPEC Consulting Ltd. (1976).

Another advantage of a portable system would be the very fact that it is portable. It could easily be moved from basin to basin within the moraine when and if it were required.

Still another factor which makes it more feasible than a major pipeline scheme is that it needn't be used in every year. It has been shown earlier in the thesis that soil moisture storage indices can be an accurate predictor of spring runoff amounts in average and wet years (Chapter V). If it could be predicted that there would be very low amounts of spring runoff there would be no need to pump and therefore no expense. Also, after an extremely wet year or in a series of wet years, if the lakes were at high enough levels that no water was needed,

there would also be no need to pump.

If interbasin transfer of water was found to be feasible, there are several locations around the moraine where surpluses from adjacent basins could easily be diverted into the major lakes of the moraine. One such area is located east of the Miquelon Lakes basin. It is an area of approximately 13.3 square kilometers (Table 6). Table 6 shows the volumes of water which might have been available for transfer in recent years. The basin is at a higher elevation than any of the Miquelon Lakes and drains off the moraine toward the east. From one point on the main creek it would be possible by ditching a distance of approximately one kilometer to divert the waters from this drainage basin into the lower Miquelon Lake. In this instance, no pumping would be necessary. Simple gravity drainage could move the surplus flows into the Miquelon Lakes basin.

Several transfer possibilities exist along the western edge of the moraine. As previously mentioned (Chapter II, Section 2.5), Clearwater Creek drains from the west side of the moraine into Blackmud Creek just north of Saunders Lake. At a point 11 kilometers west of Looking Back Lake, the creek has a drainage area of approximately 133 square kilometers. Much of the drainage area has been artificially drained for agricultural use, just as has been done in the adjacent Little Hay Lake basin. Although large quantities of water might be available for transfer (Table 6), a pumping system much more complicated than the one mentioned earlier would be necessary. The water would have to be transported a much greater distance, 11 kilometers to Looking Back Lake and then approximately four kilometers on to Joseph Lake, the closest of the moraine lakes. Along with the greater distance, there would be a

TABLE 6

POSSIBLE TRANSFERS

Transfer Site	Area (km^2)	Surpluses in Hectare Meters 1975	1974	1973	1972
Little Hay	77.2	106	1062	192	313
East Miquelon	13.3	18	183	33	54
Irvine Creek	32.4	44	445	80	131
Clearwater Creek	132.9	182	1826	341	538
West Cooking	29.4	40	405	73	119
North Cooking	11.0	15	151	27	45
Wanisan Lake	11.7	16	160	29	30

Source: Water Survey of Canada

pumping head of over 30 meters. Because of the increased volume of water, the increased distance and greater head a more elaborate pumping system would be needed if water from Clearwater Creek was to be diverted.

A much more simple, but smaller area diversion could be made from Irvine Creek. It, too, drains toward the west and into Blackmud Creek (Chapter II, Section 2.5). At a point where the creek passes under Highway 21 approximately 2.5 kilometers north of Looma, the drainage area is 32.3 square kilometers. The situation at this point is much like that of the Little Hay Lake basin. A stream tributary to the main creek has its headwaters in a slough. By ditching, the waters of the creek could be diverted to the slough. From this point the waters could be pumped over a low divide (10 meters) a distance of approximately 2 kilometers into a creek which drains to McFadden Lake. In years when there is no outflow to Cooking Lake from McFadden, additional pumping could be used to move the water.

The headwaters of Mill Creek, which empties into the North Saskatchewan River at Edmonton are on the western edge of the moraine. At a point 2 kilometers west of the junction of Highways 14 and 21 the drainage area of Mill Creek is approximately 29.4 kilometers. The waters of Mill Creek could be diverted into the McFadden Lake drainage basin and then on to Cooking Lake from this point. Again, an enlarged pumping system would be necessary to move water 8 kilometers over a 30 meter divide. From that point the waters would be in the McFadden Lake basin and would move eventually into Cooking Lake.

North of Cooking Lake there is evidence of a post glacial drainage channel. Currently Halfmoon Lake, one of the lakes located in the

channel, drains toward Cooking Lake in times of outflow. Others, such as Woodenpan Lake, drain northward into Big Island Lake and on toward the North Saskatchewan River. The creek connecting the small lakes has a very shallow gradient, and with some ditching the flow could be reversed. The waters could then be pumped about two kilometers over a 15 meter divide into Halfmoon Lake and on into Cooking Lake.

There also exists the possibility of drainage of Wanisan Lake to supplement supplies. Wanisan Lake is located in the basin of Hastings and in times of surplus precipitation there is outflow toward Hastings Lake. The divide between Wanisan and Cooking Lake is only approximately five meters. With a minor amount of ditching (2 kilometers) the waters of Wanisan Lake could be directed toward Cooking Lake. This would add approximately twelve square kilometers to the drainage area of Cooking Lake.

The areas suggested above for interbasin transfer are only a few of several. Other possibilities exist from areas east of the lakes such as from Stove Lake. Water could also be transferred to the Miquelon Lakes from areas which now drain toward the south. The possibility of transfer exists even from the main lakes. Water from Hastings Lake, which has a relatively constant level and surplus in some years, could be piped back toward Cooking Lake, a reversal of historical drainage patterns. The transfers suggested in Table 6 are not the only places of possible transfer, only a selected few to give a perspective of the possibilities.

The effect of interbasin transfer of water is to enlarge the drainage basins of the lakes of the moraine. Most of the lakes in the moraine have small drainage basin to lake area ratios. This, of course,

reduces the volume of surface runoff toward the lakes, the effect of which has been discussed previously. Hastings Lake with a large drainage area to lake area ratio has remained at fairly constant levels. By effectively enlarging drainage area to lake area ratios by interbasin transfer, the other lakes of the moraine might show a return to the balance of inflow and outflow which was present during the early part of the century.

One small type of pumping system has been suggested for the transfer of water. In some cases, such a system might not meet requirements. In these cases, more powerful pumps could be used to pump water over higher divides or longer distances. To minimize evaporation loss or eliminate the need for detention storage larger volume pumps and pipe could be used. Table 7 shows the pumping requirements and a rough estimate of costs for some of the transfer schemes suggested in Table 6.

6.3 Snow Cover Management

Another method of increasing the supply of water available to the lakes is modification of the snow cover to increase snowmelt yields. This could be accomplished by two methods, either through selected cutting of forest cover or by influencing drifting.

Selective cutting of forest areas may be used to accomplish a number of watershed management goals. Often the aim is to produce a more desirable regime. In many cases, though, selective cutting can produce increased runoff from spring snowmelt (Anderson, 1956, Connaughton, 1935, Wilm and Collett, 1940, Hibbert, 1965, Satterlund and Haupt, 1972, Haupt, 1972). Most of these studies were done in areas of coniferous forest where the procedure works best. Hoover and Leaf

TABLE 7

PUMPING REQUIREMENTS AND POSSIBLE COSTS

Basin	Pumping Distance	Head	Possible Cost (10 yrs.) Excluding right-of-way
Little Hay Lake	2.1 km	15 m	$60,000
East Miquelon	3 km	None	?
Irvine Creek	1.8 km	15 m	$55,000
Clearwater Creek	15 km	30 m	$340,000
West Cooking	8 km	30 m	$200,000
North Cooking	2 km	15 m	$55,000
Wanisan Lake	2.5 km	4 m	$60,000

Sources: Canada NTS Topographic Map 83H, Mr. Delvin Brosz, South Dakota Department of Natural Resource Development; Morris Irrigation, Ft. Pierre, South Dakota

attribute the increases in flow to three factors:

(1) A reduction in evaporation and sublimation from snow held on tree crowns (important with conifers, not as great an effect in this area with deciduous cover),

(2) less evaporation from the snowpack due to more rapid melting in open areas, and

(3) a reduction in the transpiration draft on soil moisture (e.g. change of soil moisture categories from 25 to 10 or 15 centimeters). There is another factor which should be added to the list for this area. Swanson (1972), reporting on a study done in conjunction with the Alberta Watershed Research Program, showed increased snow accumulations in small openings in aspen cover. This was the result of greater accumulation of snow in the openings due to less interception by tree crowns as well as less ablation by wind. Witter (1976) shows the patterns of snow accumulation and substantiates that there is somewhat greater accumulation especially around forest edges. With proper management, selective cutting can increase yields somewhat with a more favorable regime, beginning earlier and ending later. The increases would probably be in the order of one to two centimeters per year for the region and would be most noticeable in years of below average precipitation.

Certainly the possibility of increasing snowmelt yield by selective cutting exists in parts of the Cooking Lake moraine. The areas with the most potential are the more heavily forested areas south of Hastings Lake and east of Ministik and Oliver. While these areas may have potential for selective cutting, certain problems are inherent. In the studies mentioned above, in virtually all cases the test sites were

mountain or foothill regions where drainage is good. Because of this, the increased yield can be measured as streamflow and managed easily. The same is not true for the area south of Hastings and east of Ministik and Oliver Lakes. The main reason the area has not been cleared previously for agricultural use is the limitations of topography on agricultural production (Chapter II, Section 2.4). The area has pronounced knob and kettle topography and because of excessive slope in some cases and poor drainage in others, farming is not feasible.

If snowmelt yields were increased because of cutting, drainage improvements would have to be made as well. Unless drainage improvements were made, much of the extra yield would still go to local depression and be evaporated rather than adding anything to lake levels. Ditching would be necessary to assure that the extra yield would reach the main lakes of the moraine.

A solution which might solve the problem of making drainage improvements would be to increase snowmelt yield by influencing drifting with snow fences. Many of the studies done concerning snow fences and their effect on water yield have been done in mountain areas of the western United States (Martinelli, 1965, 1972). Martinelli (1965) determined that on two windy sites in Colorado, snow accumulation could be increased as much as one acre foot of water per 100 to 125 feet of fence. It is doubtful that accumulation could be influenced to such a great extent in the Cooking Lake area due mainly to the differences in snow amounts compared with the Colorado mountains. However, areas where significant drifting occurs have been shown to have greater surpluses than areas which lose snow because of wind ablation (Chapter V, Section 5.15) (Kakela, 1969, Witter, 1976).

To prevent the problem of loss of water to local depressions, the snow fences could be set up on the shores of the lake or actually on the lake itself. This way there would be no loss to overland flow. In addition the surplus patterns could be greatly changed since in most years the lake surfaces are subject to snow removal by the wind. McKay (in Gray, 1970) suggests that ice surfaces of lakes are able to retain only 40 to 50 per cent of the snow that falls on them (Gray, 1970, p. 221).

6.4 Phreatophyte Removal

Another means of providing extra water for the major lakes of the moraine would be the removal of phreatophytic vegetation. Phreatophytes have been described previously in Chapter V, Section 5.15. They are plants which grow where their water supply can be supplemented above normal precipitation amounts. Often this means use of groundwater. In the Cooking Lake moraine, phreatophytic vegetation is usually found as willows or aspen growing around the major lakes or in low lying areas such as around minor depressions. Here, the water supply is virtually non-limiting.

In years of adequate precipitation, phreatophytes transpire at the potential evapotranspiration rate. In dry years, however, the rate of transpiration is greater due to the amount of advected heat available from surrounding areas. Laycock (1968 and personal communication) found the value to be much the same as lake evaporation or irrigated crop, i.e. potential evapotranspiration + ½ deficit.

Phreatophyte removal has been suggested as a means for supplementing lake levels in other parts of the province (Laycock, 1968). It could have significant value in the Cooking Lake moraine as well.

The major gains would be made in dry years when lake levels suffer the most. If this were the case the inflow to the lakes in years of average and above average precipitation might be enough to maintain the balance of the early part of the century.

The extent of vegetation removal would depend on several factors including slope, drainage and type of vegetation. In addition it would be suggested that plants with shallower rooting habits be planted where phreatophytic vegetation was removed. Table 8 shows the increases which might be noticed after converting approximately five per cent of the area of the Cooking Lake moraine from 25 centimeter storage (phreatophytes) to 10 centimeters (shallow rooting grasses). The increases are marked, being over 500 hectare meters in some years. This amount of water could nearly stabilize lake levels if it could be assured that all of the surplus water reached the lakes. This conclusion was arrived at using the conclusions of EPEC Consulting Ltd. (1976) in which it was stated that approximately 10,000 acre feet (1230 hectare meters) would be necessary to stabilize lake levels after the levels are raised. These figures were based on lake level data that were exaggerated and are perhaps as much as 40 per cent too high.

The replacement grasses would be necessary to limit soil erosion by stabilizing the soil and would also limit the flow of soil nutrients toward the lake. This factor has been found to be a problem where areas have been clear cut (Pierce, et. al., 1972). Also the major increase in flow toward the main lakes should come in the form of telluric groundwater after phreatophyte removal. Because of this nutrient loadings should remain low.

The suggestion of removing forest cover to increase surface yield

TABLE 8

EFFECT OF PHREATOPHYTE REMOVAL

Cooking Lake Moraine (1795 square kilometers)

Storage	% of Area		1972		1973		1974
1.25 cm	5	x	15.1 = 75.5	x	12.6 = 63.0	x	16.0 = 80.0
5.0 cm	10	x	11.2 = 112.0	x	5.7 = 57.0	x	12.9 = 129.0
10.0 cm	35	x	6.1 = 213.5	x	3.3 = 115.5	x	12.9 = 451.5
15 cm	25	x	1.1 = 27.5	x	3.3 = 82.5	x	12.9 = 322.5
25 cm	25	x	0	x	0	x	7.1 = 177.5
Total			428.5		318.0		1160.5
Average (cm)			4.29		3.18		11.6
Ha M Total			7692		5673		20686

CHANGE AFTER PHREATOPHYTE REMOVAL

Storage	% of Area		1972		1973		1974
1.25 cm	5	x	15.1 = 75.5	x	12.6 = 63.0	x	16.0 = 80.0
5.0 cm	10	x	11.2 = 112.0	x	5.7 = 57.0	x	12.9 = 129.0
10.0 cm	40	x	6.1 = 244.0	x	3.3 = 132.0	x	12.9 = 516.0
15 cm	25	x	1.1 = 27.5	x	3.3 = 82.5	x	12.9 = 322.5
25 cm	20	x	0	x	0	x	7.1 = 142.0
Total			459.0		334.5		1189.5
Average (cm)			4.59		3.35		11.90
Ha M Total			8193		5975		21184
Increase (Ha M)			501		302		498

to the lakes has met with some opposition from wildlife preservationists when it has been mentioned earlier. If selective clearing were to be done judiciously, though, water increases could be achieved with as little disruption to the environment as possible.

6.5 Improving Drainage

Still another means of increasing the amount of water available to the major lakes would be the drainage of some wetlands and sloughs in the area. Test Site number 2 is an example of what might be done. This idea has been presented previously (EPEC, 1971 and 1976, Stanley, 1974), but has always been rejected because of the detrimental effects on waterfowl. It was felt that draining some of the small sloughs in the area would destroy valuable staging areas. In very dry years though, the sloughs are nearly dry and of virtually no use to waterfowl and consolidation of the limited supplies could be advantageous. The major lakes of the moraine are fast approaching the same state. With the addition of water from areas in the basins which do not normally contribute to the main lakes, significant changes in the water balance of the lake basins are possible.

In most cases, the drainage improvements necessary would involve only ditching to drain such areas as Coleman and Sisib Lakes or even the slough of test plot number 1 toward Cooking Lake. Again, the effect would be enlargement of the drainage area to lake area ratio, an effect which has been previously discussed. Referring back to Table 4 (Chapter V), drainage in the Hastings Lake basin has kept its drainage area to lake area ratio at least 5:1. If areas of the Cooking Lake basin could be drained to keep the ratio at a constant 3 or 4:1, the result would be addition of up to 150 to 200 hectare meters in some

years, mainly the drier years.

6.6 Summary

The exact amounts of water necessary to stabilize the levels of each lake are difficult to determine. Certainly, the amounts would vary from lake to lake. Yearly amounts would vary as well. In many cases, a variation in level from year to year would be more effective in controlling algal growth than having a stabilized level. It is apparent that the amounts of water necessary to improve lake levels are exaggerated.

This chapter has included suggestions of alternative means of obtaining water supply for the major lakes of the Cooking Lake moraine. There are others which have been mentioned previously, such as evaporation suppression (EPEC, 1971, Stanley, 1974) which were not discussed here. In most cases the costs of some of these methods would be prohibitive. Bruce and Clark (1966) suggest that using hexadeconal to reduce evaporation runs the cost of water saved to approximately $40 per acre foot at 1966 prices.

The ideas presented in this chapter are valid water supply alternatives which have not previously been given serious consideration in deference to the more grandiose transfer schemes. It is felt by the author that these schemes are viable and economically much more feasible than a more major transfer project.

CHAPTER VII

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

7.1 Summary

The Cooking Lake Moraine, located in close proximity to the city of Edmonton, is an area which could provide recreational opportunities for an expanding urban area. Declining lake levels and deteriorating water quality in the area have caused the recreation potential of the moraine to decline severely. This overall deterioration of the lakes has had detrimental effects on water based recreation and has affected wildlife and urban expansion in some ways. In some areas though, the decline in water levels has allowed agricultural expansion in areas which were once flooded and the area continues to be subdivided for urban expansion.

Several means of supplementing the water supplies of the lakes of the moraine have been suggested. This study was intended as an examination of the availability of snowmelt runoff to add to lake levels. In order to make the study more complete, other possible water supply alternatives were studied and reviewed.

The objectives of the author in this study were to more accurately define the parameters of the water balance in the study area and to interpret the results. The major techniques to be used were those described by C. W. Thornthwaite. By studying the surplus and deficit patterns of the water balance of the area, it was hoped that more accurate understanding and predictions of the patterns would provide an insight into how they might be managed to return the lakes to a balance better suited for more intensive uses. In order to study the patterns more closely, ten sub-basins were chosen for more intensive study. In

these test basins the spring snowmelt runoff was gauged in an attempt to see how closely the measured surplus patterns followed those predicted using Thornthwaite calculations.

As a necessary part of this study, the physical characteristics of the study area were analyzed in Chapter II. Bedrock and surficial geology, topography, drainage patterns, soils, climate and vegetation were reviewed and their effects on the water balance were discussed. In this chapter, the Thornthwaite water balance procedures were explained and the patterns of each coefficient were discussed.

Certainly, historical and land use perspectives are important parts of any study and Chapter III is a review of some of the historical patterns of development in the moraine area. The history of drainage patterns and lake levels since glaciation is varied. Conditions have ranged from very dry times to wetter times when there was a chain of drainage joining most of the lakes in the moraine. Chapter III also includes a review of the actions taken to restore the lake levels, beginning in 1971 with a petition from area residents expressing concern over the declining lake levels. The effects of several possible management policies which have been suggested as a result of governmental commission studies were also discussed.

In Chapter IV, each of the individual test plots was analyzed as to its land use. After analyzing land uses, these were further divided into soil moisture storage categories. With this information, predictions of runoff amounts were made for both field seasons. It was predicted that because of below average precipitation, very little runoff could be expected with much of the runoff coming from roads, railway grades or other areas of low storage. These predictions were made

assuming several things which could have affected the final results. First, Edmonton International Airport data were used for the meteorological information and moraine conditions could have been different. Since the moraine area is higher, precipitation amounts could have been somewhat higher and the potential evapotranspiration values may have been somewhat less. Second, the predictions of runoff were made with no adjustment for the effect of drifting. In the Prairies of Canada, the effect of drifting can have a great effect on spring snowmelt runoff volumes, especially in years of little or no average surplus as indicated by use of water balance calculation procedures.

Chapter V was a description and analysis of the field measurements from the 1975 and 1976 snowmelt seasons. In both years, runoff exceeded the predicted amounts at seven of the ten test sites. One site had lower than predicted volume and at two sites no flow was recorded at all. The runoff patterns were analyzed for both years and an attempt was made to explain the greater than expected volumes. A comparison was also made of the two very different melt seasons. The first was a late season yield with rapid melting, while the 1976 season was a long one with slower melting and greater infiltration. In addition, water quality samples were analyzed to determine the effects of runoff waters on lake water qualities. Also, an attempt was made to explain the anomalous balance of Hastings Lake. It has remained at relatively high levels while all of the other lakes in the moraine area have declined in level in most years.

In response to and as a comparison with the major water supply schemes which had been suggested, Chapter VI was a discussion of some alternative, smaller scale management possibilities. These included

minor transfer from neighboring basins, snow cover management for increased yields, phreatophyte removal and artificial drainage of sub-basins which contribute little or nothing to the major lakes.

7.2 Conclusions

In both of the field seasons, the conditions were such that the expected surpluses using Thornthwaite prediction techniques were exceeded by runoff. The summers before each field season were dry and in both years, winter precipitation was inadequate to recharge soils to even the 10 centimeter soil moisture storage level. Using these data, unadjusted for drifting influences, the only surpluses which could be predicted were at the 1.25 and 5 centimeter levels and sub-basin yields of .05 to .8 centimeters in 1975 and from .03 to .5 centimeters in 1976 were forecast.

The actual runoff patterns were greatly different, however. In 1975, runoff amounts ranged from an average yield of 4.1 centimeters at Site 1 to no flow from Sites 4 and 5. In 1976, amounts ranged from over 6 centimeters at Site 1 to no flow at Sites 4 and 5 again. Although these yields are low in comparison with those of the three previous years, especially 1974, they do indicate that allowances must be made for variables that are not adequately considered in an unadjusted water balance calculation.

The first major influence is the climatic conditions during the melt seasons. The amounts of surplus predicted for both seasons were very nearly the same; however, the amounts measured in 1975 exceeded those in 1976 due partially to differing melt season temperatures.

In 1975 the snowmelt began in late April. This was somewhat later than usual, so when temperatures did warm due to the influence of

Pacific air masses, the daily temperatures warmed quickly. This allowed the snow to ripen and run off quickly before the ground had time to thaw completely. In 1976, though, the melt began in mid-March and continued until mid-April. The slow rise in daily temperatures allowed a slow ripening of the snowpack and thawing of the ground, thus allowing maximum infiltration.

In 1975 especially and perhaps somewhat in 1976, groundwater flow probably affected the amounts of runoff recorded. This was certainly true in basins 1, 2 and 3. Groundwater flow was predictably large because of carryovers from previous wet years. The only evidence of groundwater flow was a lengthened hydrograph and therefore total volume was difficult to evaluate exactly. While groundwater flow may be a major part of flows toward the lakes in years of below average precipitation (especially following wet years), the effect on the long term yield patterns would be much less evident.

Another factor which greatly influenced runoff amounts was snow drifting patterns. Drifting effectively increased the precipitation on some areas and decreased it in others. Because of this, some local areas in storage categories which were expected to show no surplus actually registered runoff because of drifting patterns. These drift areas were usually along drainage channels where there was low potential for additional storage, so much of the surplus showed up directly as runoff.

The effect of drifting is much more evident in dry years. In wet years, when there is adequate precipitation to recharge all soil moisture storage levels, the redistribution of precipitation due to drifting has very little effect on surplus patterns. There is still enough

precipitation to recharge soil moisture storage capacities and the surplus precipitation still goes as runoff. However, in dry years when only enough precipitation is received to recharge the 10 centimeter storage capacity, any redistribution of the snow cover has a marked effect. Areas of 10 centimeter storage from which snow had drifted could experience up to 5 centimeters of additional deficit. Conversely, an area of 10 centimeter storage capacity which received drifting might then show a 5 centimeter surplus when none was predicted. The following equations point up the effects drifting may have on a dry year water balance (using a 10 centimeter soil moisture storage value).

Values in centimeters	P		PE	D	S	SC
Average	42.5	=	(52.5 - 10)	+ 0	$\pm$ 0	
Area from which snow has drifted	42.5 - 5.0	=	(52.5 - 15)	+ 0	$\pm$ 0	
Drift Areas	42.5 + 5.0	=	(52.5 - 10)	+ 5.0	$\pm$ 0	

These equations assume that the area from which snow is drifted is equal to the area which receives drifting. This is seldom the case, however, since drifted snow is concentrated in a very small area. Because of this, local surpluses may be extremely large in drift areas. Thornthwaite procedures can be used accurately in dry years, but much more attention must be given to specific site characteristics, especially in terms of snow drifting.

Lake level fluctuations were also used to correlate the runoff amounts. The data from the previous years, 1972, 1973 and 1974, showed a relatively good correlation between the predicted spring surpluses using Thornthwaite techniques and the fall to spring lake level rises. The same was done for both study years. The resultant lake level rises

were used to calculate the total basin average yield. Comparing these figures with the measured runoff data and using field observations, it was possible to estimate the ratio of drainage basin to lake area ratios for the study years. For Cooking Lake the ratio varies from approximately 2 or 3 to one in dry years to as much as 5 to one in wet years. Hastings Lake, however, has a much more constant ratio of at least 5 to one, and probably a greater ratio in wet years.

The Hastings Lake basin seems to have other features which keep its level more stable than the others. One is the fact that through artificial drainage the effective drainage basin area has been increased. Also, clearing patterns, groundwater flow and better surface drainage may contribute to the anomalous balance of Hastings Lake.

It was assumed at the outset of the study that the quality of snowmelt water would be relatively good and would not have any detrimental effects on the main lakes. From the samples taken in 1976, this was not the case. All samples were high in nutrient content, enough that the loadings could have caused increased growth. The waters tested, however, were the equivalent of very late season flows in average and wet years and, in this light, could be expected to be poor. Other area studies show that early season meltwater is of relatively good quality.

This study was originally intended to examine the feasibility of a type of internal water management, snow cover management, in raising lake levels of the moraine. Although low surpluses in both years affected the field results, using previous years' records and reports from other area studies, the author was able to evaluate the possible effects of several different management schemes.

The study years showed that even in years of below average precipitation there are surpluses due to drifting. In many cases, though, this surplus flow never reaches the main lakes. If drifting could be induced on or near the main lakes, the increase in surplus in years of below average precipitation could cause a change in the overall balance of the lakes.

Transpiration from phreatophytes, especially in dry years, decreases the amount of surplus available to the main lakes. In areas of phreatophyte losses, if these plants were removed and replaced by shallower rooting plants, there might be notable increases in surface and groundwater runoff toward the main lakes, again, most noticeable in dry years.

Also, many of the basins surrounding the Cooking Lake moraine show surpluses in many years. This is due to several factors including different land uses and better surface drainage. In several places it would be a simple matter to pump some of these surplus flows via a portable pipeline, or in some cases simple gravity drainage would suffice, into the neighboring lake basin within the moraine system. In terms of volume, this supply alternative would have the greatest effect on the moraine lakes and this effect would be most evident in wet years.

In terms of overall objectives for water use in the moraine, these alternatives could be viable. They would provide higher lake levels, but still with some fluctuation which is necessary for wildlife and improved quality. The costs would be much less than for major transfers and for most purposes, supplies would be adequate.

7.3 Recommendations for Research and Management

Through the course of the study a number of observations were made concerning possible research and management opportunities for the study area.

7.3.1 Research

Initially it was felt by the author that it was unfortunate that the field seasons selected for this study experienced below average precipitation. While the results of the study proved interesting and gave insight into the surplus patterns in years of below average precipitation, the findings concerning necessary adjustment to account for increased runoff because of drifting could not be applied confidently in years of normal or above normal precipitation. Because of this and also to give a better overall picture, it is suggested that the study be carried out in a year or years of greater precipitation. Thornthwaite techniques have been applied accurately to this area and with very little monitoring of soil moisture indices, spring surpluses could be checked in such years using the procedures described in this thesis.

If Thornthwaite procedures are to be refined for use in this area, more accurate meteorological records are desirable. The data used in this study were from the Edmonton International Airport. While these data are probably adequate for use in the moraine area, the difference in elevation between the airport and the moraine (the moraine being slightly higher) may cause slightly higher precipitation amounts and slightly lower potential evapotranspiration amounts. A difference of only one centimeter in each direction in a one year period could account for a total of two centimeters of increased runoff.

7.3.2 Management

Perhaps the most important suggestions might be made in the areas of water supply alternatives and internal management. Some alternative methods of improving supply including snow cover management, phreatophyte removal and minor transfer have been suggested, but none has ever been tested specifically as to its viability. In practice the alternatives of draining local depressions and making favorable land use changes are being inadvertently tested in the Hastings Lake basin and are being found effective.

Since the beginning of studies on the moraine area, only major, large scale transfers have been given any serious consideration. The initial calculations concerning yield and cost figures for the management and supply alternatives suggested in this thesis show that these schemes could be viable. No testing of their physical potential was possible. It would be simple to test some of these management alternatives on nearly a research basis. Minor test basins could be used, if necessary, to get estimates of overall potential.

Up to this time, most of the studies concerning the possible increased yields from snow cover management by influencing drifting or selective cutting have been done in mountain areas. It appears that increased yields could be obtained in the Cooking Lake moraine through induction of drifting. If part of the moraine area were managed for increased water yields in this manner, the information could prove valuable for future management here and elsewhere.

Phreatophyte removal, too, has been shown to provide greater surpluses in other areas of North America, but no studies have been done in the Prairies of Canada with the objective of increasing groundwater

yields. Again, it appears as though there could be some success with increased yields in the Cooking Lake moraine area. If the results were positive, these studies could be applied to other areas.

Finally, the idea of minor transfer of water could provide hundreds of hectare meters of surplus water in the wetter years to the major lakes of the moraine. The cost would be much less than a large scale transfer scheme and using a basin such as the Little Hay Lake-Miquelon transfer in a few years as a test could prove that such major transfers are not needed. If this alternative proved effective it might have applications in other areas as well.

It is evident that during certain times in the past the lakes of the moraine have maintained a balance that kept them at levels at which recreation was feasible. The Hastings Lake basin experience is a good indicator that perhaps only minor changes could result in a return of other lakes to this balance. These changes could result in environmental enhancement with respect to recreation, wildlife and other objectives. In addition to meeting these objectives they could accomplish similar results to those of a pipeline-pumping scheme and at a much lower cost. In this light, if these suggested management alternatives could return the lakes to their one-time balance, such a major irreversible scheme as large scale transfer would seem almost foolhardy.

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APPENDIX A

WATER BALANCE TABLES

Water Balance for Edmonton Namao A 1952-1974

(Thornthwaite procedures using 10 cm storage level)

Metric Conversions

	Precipitation	=	(P.E.cm - Dcm)	+	Surplus cm	± Storage Change cm
1957	35.0	=	(53.8 - 25)	+	0	+ 6.3
1958	44.8	=	(55.3 - 18)	+	6.3	+ 1.3
1959	45.3	=	(46.5 - 3.5)	+	3.3	- 1
1960	47.3	=	(53.0 - 4.3)	+	2	- 3.5
1961	44.0	=	(54.3 - 13.3)	+	2.5	+ .5
1962	42.3	=	(53.8 - 16.5)	+	8	- 3
1963	28.8	=	(55.5 - 27.5)	+	1.5	- .8
1964	39.8	=	(55.3 - 19.3)	+	0	+ 3.8
1965	52.8	=	(51.8 - 9.8)	+	13.5	- 2.8
1966	38.0	=	(49.0 - 11.5)	+	1.3	- .8
1967	35.0	=	(52.3 - 22.3)	+	1.3	+ 3.8
1968	36.0	=	(49.8 - 13.0)	+	1	- 1.8
1969	44.8	=	(52.0 - 11.8)	+	.25	+ 4.3
1970	43.8	=	(53.3 - 11.3)	+	4	+ 2.3
1971	39.8	=	(54.5 - 18.5)	+	3	+ .8
1972	50.5	=	(49.5 - 5)	+	7.8	+ 1.8
1973	56.5	=	(54.5 - 1.5)	+	0	+ 3.5
1974	54.5	=	(52.0 - 2.5)	+	9.5	- 4.5
	43.3	=	(52.5 - 13)	+	3.5	+ .3

Source: Edmonton International Airport Monthly Meteorological Records

Water Balance for Edmonton International Airport 1962-1974

(Thornthwaite procedures using 10 cm storage level)

Metric Conversions

	Precipitation	=	(P.E.cm - Dcm)	+	Surplus cm	±Storage Change cm
1962	53.4	=	(53.0 - .8)	+	6.0	- 4.8
1963	41.5	=	(54.5 -14.8)	+	3.0	- .3
1964	44.0	=	(49.8 - 9.0)	+	0	+ 3.3
1965	55.8	=	(48.8 - 1.5)	+	10.8	- 2.3
1966	40.8	=	(47 - 4.3)	+	1	- 3
1967	33.0	=	(49.5 -19.3)	+	.75	+ 2
1968	34.5	=	(45.3 - 9)	+	0	- 1.8
1969	45.5	=	(48.5 - 9)	+	0	+ 6
1970	17.5	=	(50.5 - 9.5)	+	4.8	+ .5
1971	40.5	=	(51 -14.3)	+	5	- 1.8
1972	55	=	(46 - 0)	+	6	+ 3
1973	57.5	=	(50.3 - 0)	+	5	+ 2.3
1974	46.8	=	(50.3 - 6.3)	+	11.8	- 9
	45.5	=	(49.6 - 7.5)	+	4.2	- .8

Source: Edmonton International Airport Monthly Meteorological Records

Water Balance for Edmonton Industrial Airport 1950-1974

(Thornthwaite procedures using 10 cm storage level)

Metric Conversions

	Precipitation	=	(P.E.cm - Dcm)	+	Surplus cm	± Storage Change cm
1950	32.3	=	(51.3 - 18.8)	+	0	- .3
1951	51.0	=	(48.8 - 5.5)	+	3.8	+ 4.8
1952	41.0	=	(58.3 - 15.5)	+	4.3	- 6
1953	63.8	=	(56.3 - 0)	+	5.3	+ 2.3
1954	49.8	=	(49.8 - 0)	+	1.8	- 1.8
1955	50.3	=	(57.3 - 14.5)	+	3.0	+ 4.5
1956	50.3	=	(56.3 - 8.5)	+	6.3	+ 3.8
1957	32.8	=	(55.8 - 25)	+	0	+ 2.0
1958	43.0	=	(60.8 - 18)	+	2.0	- 1.8
1959	44.0	=	(52.5 - 9.3)	+	0	+ .8
1960	49.0	=	(56.5 - 6)	+	0	- 1.5
1961	31.0	=	(58.8 - 25)	+	0	- 2.8
1962	46.0	=	(55.5 - 11.5)	+	2.5	- .5
1963	33.5	=	(59.3 - 24.8)	+	.5	- 1.5
1964	40.3	=	(57.0 - 20.0)	+	0	+ 3.3
1965	53.5	=	(54.3 - 10.5)	+	12	- 2.3
1966	38.8	=	(54.5 - 15.3)	+	0	- .5
1967	38.5	=	(56.8 - 22.5)	+	1.8	+ 1.8
1968	33.5	=	(55.5 - 19.8)	+	0	- 2.3
1969	47.3	=	(56.8 - 12.3)	+	0	+ 3.3
1970	46.3	=	(60.3 - 14)	+	1	- 1
1971	39.5	=	(59.3 - 22)	+	1.5	+ .8

Water Balance for Edmonton Industrial Airport 1950-1974

(continued)

	Precipitation	=	(P.E.cm - Dcm) +	Surplus cm	± Storage Change cm
1972	50.8	=	(53.8 - 7) +	6.3	- 2.3
1973	54.8	=	(54.5 - 2.3) +	0	+ 3
1974	52.0	=	(53.0 - 3.5) +	6.3	- 3.8
	44.5	=	(55.8 - 13.3) +	2.3	+ 0

Source: Edmonton Industrial Airport Monthly Meteorological Records

Water Balance for Camrose 1951-1974

(Thornthwaite procedures using 10 cm storage level)

Metric Conversion

	Precipitation	=	(P.E.cm - Dcm)	+	Surplus cm	± Storage Change cm
1951	42.3	=	(49.8 - 9.8)	+	2.3	+ 0
1952	33.8	=	(54.5 - 17.8)	+	0	+ 3
1953	46.5	=	(50.5 - 6.8)	+	0	+ 2.8
1954	55.0	=	(46.0 - 0)	+	8.5	+ .5
1955	40.5	=	(51.8 - 13)	+	.5	+ 1.3
1956	41.8	=	(51.0 - 9.5)	+	1.5	- 1.3
1957	37.8	=	(52.8 - 14.5)	+	0	- .5
1958	28.5	=	(53.5 - 25)	+	0	+ 0
1959	41.3	=	(50.0 - 13.8)	+	0	+ 5
1960	--	=	-- --		--	--
1961	--	=	-- --		--	--
1962	--	=	-- --		--	--
1963	--	=	-- --		--	--
1964	--	=	-- --		--	--
1965	--	=	-- --		--	--
1966	45.5	=	(51.5 - 7.5)	+	0	+ 1.5
1967	33.5	=	(53.5 - 23.8)	+	1.8	+ 2.3
1968	34.0	=	(50.5 - 14)	+	0	- 2.5
1969	45.3	=	(54.0 - 14.8)	+	.5	+ 5.5
1970	42.3	=	(56.0 - 17)	+	6.3	- 3
1971	35.8	=	(53.8 - 20.5)	+	3.5	- 1

Water Balance for Camrose 1951-1974

(continued)

	Precipitation	=	(P.E.cm - Dcm)	+	Surplus cm	±Storage Change cm
1972	51.5	=	(52.3 - 8)	+	7.8	- .5
1973	72.3	=	(50.8 - 0)	+	13.3	+ 8.3
1974	50.3	=	(50.3 - 9.5)	+	19.3	- 9.8
	43.3	=	(51.8 - 12.5)	+	3.5	+ .5

Source: Edmonton International Airport Monthly Meteorological Records

Water Balance for Vegreville CDA 1964-1974

(Thornthwaite procedures using 10 cm storage level)

Metric Conversion

	Precipitation	=	(P.E.cm - Dcm)	+	Surplus cm	±Storage Change cm
1964	34.5	=	(50.3 - 20.3)	+	0	+ 4.8
1965	46.3	=	(50.3 - 4.8)	+	2	- 1.3
1966	28.0	=	(51.0 - 22.3)	+	0	- 1
1967	29.5	=	(50.5 - 22.8)	+	0	+ 1.8
1968	35.5	=	(47.3 - 11.3)	+	0	- .5
1969	33.5	=	(53.5 - 21.3)	+	0	- 1.3
1970	37.8	=	(51.5 - 14.8)	+	0	+ 1
1971	36.3	=	(52.0 - 15.0)	+	0	- .8
1972	39.3	=	(48.0 - 9.8)	+	1.5	- .5
1973	53.8	=	(51.8 - 2.3)	+	0	+ 4.3
1974	39.0	=	(49.8 - 9.3)	+	4.8	- 6.3
	37.5	=	(50.5 - 14)	+	.8	+ .2

Source: Edmonton International Airport Monthly Meteorological Records

APPENDIX B

YEARLY WATER BALANCE TABLES

Edmonton International - Long Term Normal

*		J	F	M	A	M	J	J	A	S	O	N	D	YEAR
	°C	-16.3	-12.3	-6.3	3.5	9.7	13.3	16.1	14.4	9.7	4.2	-5.5	-12.3	
	PE (cm)				2.53	6.98	9.18	11.30	10.33	5.56	2.75			48.63
	Ppt. (cm)	2.30	1.85	2.25	2.65	3.43	7.53	9.78	6.53	4.30	1.85	1.83	1.83	46.13
	S.C.	2.30	1.85	2.25	.12	-3.55	-1.65	-1.52	-3.80	-1.26	-.90	1.83	1.83	
	St. 1.25	1.25	1.25	1.25	1.25	0	0	0	0	0	0	1.25	1.25	
2.41	Surplus	2.30	1.85	2.25	.12	-	-	-	-	-	-	.58	1.83	8.93
	Deficit					2.30	1.65	1.52	3.80	1.26	.90			11.43
3.66	St. 5 cm	5.00	5.00	5.00	5.00	1.45	0	0	0	0	0	1.83	3.66	
	Surplus	.96	1.85	2.25	.12									5.18
	Deficit						.20	1.52	3.80	1.26	.90	0	0	7.68
3.66	St. 10 cm	5.96	7.81	10.00	10.00	6.45	4.80	3.28	0	0	0	1.83	3.66	
	Surplus			.06	.12									.18
	Deficit								.52	1.26	.90			2.68
3.66	St. 15 cm	5.96	7.81	10.06	10.18	6.63	4.98	3.46				1.83	3.66	
	Surplus													0
	Deficit								.34	1.26	.90			2.50
3.66	St. 25 cm	5.96	7.81	10.06	10.18	6.63	4.98	3.46				1.83	3.66	
	Surplus													0
	Deficit								.34	1.26	.90			2.50

* Storage carryover

Edmonton International - 1972

*		J	F	M	A	M	J	J	A	S	O	N	D	YEAR
	°C	-19.5	-16.7	-6.2	2.6	11.0	14.6	13.4	16.4	5.6	2.7	-4.5	-15.9	
	PE (cm)				1.73	7.98	11.23	10.28	11.25	3.98	1.38			47.83
	Ppt. (cm)	1.98	3.08	3.03	3.83	4.90	10.48	8.68	9.30	4.70	1.05	2.73	1.38	55.14
	S.C.	1.98	3.08	3.03	2.10	-3.08	-.75	-1.60	-1.95	.72	-.33	2.73	1.38	
	St. 1.25	1.25	1.25	1.25	1.25	-	-	-	-	.72	.39	1.25	1.25	
4.63	Surplus	1.98	3.08	3.03	2.10	-	-	-	-			1.87	1.38	14.82
	Deficit					1.83	.75	1.60	1.95					6.13
	St. 5 cm	5.00	5.00	5.00	5.00	1.93	1.18	-	-	.72	.39	3.12	4.50	
.88	Surplus	1.98	3.08	3.03	2.10	-	-	-	-	-	-	-	-	11.07
	Deficit							.43	1.95					2.38
5.88	St. 10 cm	7.86	10.00	10.00	10.00	6.92	6.17	4.57	2.62	3.34	3.01	5.74	7.12	
	Surplus		.94	3.03	2.10									6.07
	Deficit													0
5.88	St. 15 cm	7.86	10.94	13.97	15.00	11.92	11.17	9.57	7.62	8.34	8.01	10.74	12.12	
	Surplus				1.07									1.07
	Deficit													0
5.88	St. 25 cm	7.86	10.94	13.97	16.07	12.99	12.24	10.64	8.69	9.41	9.08	11.81	13.19	
	Surplus													0
	Deficit													0

* Storage carryover

Edmonton International - 1973

*		J	F	M	A	M	J	J	A	S	O	N	D	YEAR
	°C	-12.4	-11.2	-2.9	2.5	11.1	13.9	15.5	14.8	10.0	3.6	-14.8	-12.9	
	PE (cm)				1.73	7.98	10.20	11.30	10.33	5.58	2.08			49.20
	Ppt. (cm)	1.20	1.05	1.05	4.55	3.65	14.53	8.65	10.88	3.38	3.30	2.83	2.55	57.62
	S.C.	1.20	1.05	1.05	2.82	-4.33	4.33	-2.65	.55	-2.20	1.22	2.83	2.55	
	St. 1.25	1.25	1.25	1.25	1.25	0	1.25	0	.55	0	1.22	1.25	1.25	
3.25	Surplus	1.20	1.05	1.05	2.82	-	3.08	-	-	-		2.80	2.55	12.45
	Deficit					3.08	-	1.40	-	1.65				6.13
4.50	St. 5 cm	5.00	5.00	5.00	5.00	.67	5.00	2.35	2.90	.70	1.92	4.75	5.00	
	Surplus	.70	1.05	1.05	2.82	-	-	-	-	-	-	-	2.30	5.62
	Deficit													0
7.12	St. 10 cm	8.32	9.37	10.00	10.00	5.67	10.00	7.35	7.90	5.70	6.92	9.75	10.00	
	Surplus			.42	2.82								2.30	3.24
	Deficit													0
12.12	St. 15 cm	13.32	14.37	15.00	15.00	10.67	15.00	12.35	12.90	10.70	11.92	14.75	15.00	
	Surplus			.42	2.82								2.30	3.24
	Deficit													0
13.19	St. 25 cm	14.39	15.44	16.49	19.31	14.98	19.31	16.66	17.21	15.01	16.23	19.06	21.61	
	Surplus													0
	Deficit													0

* Storage carryover

Edmonton International - 1974

*		J	F	M	A	M	J	J	A	S	O	N	D	YEAR
	°C	-18.9	-10.7	-12.1	2.6	8.1	14.6	15.1	12.7	8.7	6.7	2.8	-5.9	
	PE (cm)				1.73	5.98	11.23	11.30	8.45	5.58	3.45			47.72
	Ppt. (cm)	4.27	2.05	3.93	1.43	3.95	11.48	8.70	4.82	3.08	.43	.28	2.10	46.52
	S.C.	4.27	2.05	3.93	-.30	-2.03	.25	-2.60	-3.63	-2.50	-3.02	.28	2.10	
	St. 1.25	1.25	1.25	1.25	.95	0	.25	0	0	0	0	.28	1.25	
5.35	Surplus	4.27	2.05	3.93	-	-	-	-	-	-	-	-	1.13	15.60
	Deficit					1.08	-	2.35	3.63	2.50	3.02	0		12.58
	St. 5 cm	5.00	5.00	5.00	4.70	2.67	2.92	.32	0	0	0	.28	2.38	
2.30	Surplus	4.27	2.05	3.93	-	-	-	-	-	-	-	-	-	12.55
	Deficit								3.31	2.50	3.02			8.83
	St. 10 cm	10.00	10.00	10.00	9.70	7.67	7.92	5.32	1.69	0	0	.28	2.38	
2.30	Surplus	4.27	2.05	3.93						-	-			12.55
	Deficit									.81	3.02			3.83
	St. 15 cm	15.00	15.00	15.00	14.70	12.67	12.92	10.32	6.69	4.19	1.17	1.45	3.55	
2.30	Surplus	4.27	2.05	3.93										12.55
	Deficit													0
21.61	St. 25 cm	25.00	25.00	25.00	24.70	22.67	22.92	20.32	16.69	14.19	11.17	11.45	13.55	
	Surplus	.88	2.05	3.93										6.86
	Deficit													0

* Storage carryover

Edmonton International - 1975

*		J	F	M	A	M	J	J	A	S	O	N	D	YEAR
	°C	-12.1	-15.8	-9.7	-.9	9.6	12.9	17.2	12.3	10.5	3.0	-4.7	-11.9	
	PE (cm)					6.98	9.18	12.33	8.45	6.35	1.38			44.67
	Ppt. (cm)	1.20	1.50	1.68	2.93	5.00	10.10	6.78	9.68	1.10	2.38	.60	2.53	45.48
	S.C.	1.20	1.50	1.68	2.93	-1.98	.92	-5.55	1.23	-5.25	1.00	.60	2.53	
	St. 1.25	1.25	1.25	1.25	1.25	0	.92	0	1.23	0	1.00	1.25	1.25	
1.13	Surplus	1.20	1.50	1.68	2.93	-	-	-	-	-	-	.35	2.53	8.44
	Deficit					.73	-	4.63	-	4.02				9.38
2.38	St. 5 cm	3.58	5.00	5.00	5.00	3.02	3.94	0	1.23	0	1.00	1.60	4.13	
	Surplus		.08	1.68	2.93	-	-	-	-	-				4.69
	Deficit							1.61		4.02				5.63
2.38	St. 10 cm	3.58	5.08	6.76	9.69	7.71	8.63	3.08	4.31	0	1.00	1.60	4.13	
	Surplus													0
	Deficit									.94				.94
3.55	St. 15 cm	4.75	6.25	7.93	10.86	8.88	9.80	4.25	5.48	.23	1.23	1.83	4.36	
	Surplus													0
	Deficit													0
13.55	St. 25 cm	14.75	16.25	17.93	20.86	18.88	19.80	14.25	15.48	10.23	11.23	11.83	14.36	
	Surplus													0
	Deficit													0

* Storage carryover

Edmonton International - 1976

*		J	F	M	A	M	J	J	A	S	O	N	D	5 MONTHS
	°C	-12.5	-8.8	-6.0	6.3	13.0								
	PE (cm)				4.33	8.98								
	Ppt (cm)	1.11	2.15	1.59	1.17	1.65								
	S.C.	1.11	2.15	1.59	-3.16	-7.33								
	St. 1.25	1.25	1.25	1.25	0	0								
2.88	Surplus	1.11	2.15	1.59	-	-							3.04"	7.73
	Deficit				1.91	7.33								9.24
4.13	St. 5 cm	5.00	5.00	5.00	3.09	0								
	Surplus	.24	2.15	1.59	-	-							1.45"	3.98
	Deficit					4.24								4.24
4.13	St. 10 cm	5.24	7.39	8.98	5.82	0								
	Surplus													0
	Deficit					1.51								1.51
4.36	St. 15 cm	5.47	7.62	9.21	6.05	0								
	Surplus													0
	Deficit					1.28								1.28
14.36	St. 25 cm	15.47	17.62	19.21	16.05	8.72								
	Surplus													0
	Deficit													0

* Storage carryover

APPENDIX C

METRIC CONVERSION TABLES

METRIC	ENGLISH
Length	**Length**
Meter = 1.093 yards 3.281 feet 39.370 inches Kilometer = 0.621 mile	Foot = 0.3048 meter Inch = 0.0254 meter Inch = 2.54 centimeters Mile = 1.609 kilometers
Surface	**Surface**
Square meter = 10.764 square feet Square kilometer = 0.386 square mile Hectare = 2.471 acres	Square foot = 0.092 square meters Square mile = 2.590 square kilometers Acre = 0.405 hectare
Volume	**Volume**
Cubic meter = 35.314 cubic feet Hectare meter = 8.130 acre feet	Cubic foot = 0.028 cubic meter Acre foot = 0.123 hectare meter
Discharge	**Discharge**
1 cubic meter per second = 35.31 cubic feet per second	1 cubic foot per second = 0.02832 cubic meters per second